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PROJECT SELECTION: SOLID WASTE DISPOSAL MANAGEMENT

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

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Philip J. Sands

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SUMMARY

Decision making in solid waste disposal management has become more difficult and complex. This is a result of the increased interest of the public, new methods of disposal being introduced, and the addition of constraining laws bearing directly on the disposal system. The objective of this research is to aid the decision makers at the local government level in choosing among disposal alternatives by developing a logical selection procedure which can be used to evaluate the worth of various alternatives and enable the decision makers to establish a preference listing.

In developing a selection model, the various approaches now in use were examined for their applicability in this subject area. The model that was developed is a multi-dimensional scoring model. The scoring model affords the decision makers the opportunity to combine in exacting fashion both qualitative and quantitative factors that affect decisions. A scoring model is a ranking procedure which utilizes relevant weighted criteria to evaluate alternatives. A composite score is obtained by the use of a decision matrix and the alternatives are ranked in order of worth.

The criteria utilized in the model were selected for their relevancy, completeness, measurability, and independence. The criteria were examined in detail, performance measures were determined, and an evaluation procedure for each criterion was outlined. Those criteria which

were qualitative required subjective evaluation. Once the model was fully developed and explained, an example of its use was given.

Throughout the entire research, the goal of developing a selection model usable by decision makers at the local government level was kept paramount. The scoring model develops a rational decision procedure which can be understood and easily used. By utilizing the scoring model, the decision makers are forced to follow a set pattern in researching for the data that are included in the decision process. The scoring model broadens the scope of the decision research as it incorporates the technical knowledge of the civil servant technician with the political knowledge of the decision makers. The scoring model's true value will most probably be found in the wide range of information it can generate for use in making selection decisions.

CHAPTER I

INTRODUCTION

Objectives

This study is concerned with the nature of decision making at the local government level, especially in the area of project selection of various solid waste disposal methods. The primary objective is to develop a logical selection procedure which can be used to evaluate the "worth" of various alternatives and enable the decision makers to establish a preference listing of the alternatives based upon multi-dimensional selection criteria. A secondary objective is to gain an understanding of the various problems confronting a decision maker in the area of solid waste disposal management.

Importance of the Problem

By the year 2000, the population of the United States is expected to double. The cities and their surrounding suburbs are already bearing the brunt of this explosive growth. This growth, coupled with the increasing per capita rate of refuse production, is resulting in an ever-increasing volume of solid wastes that must be regularly collected, transported, and ultimately disposed of. Figures 1 and 2 display the long term trend in total refuse production and per capita refuse production (1).

For too long, the growing problem of solid waste disposal has been relegated to a subordinate position among community and environmental

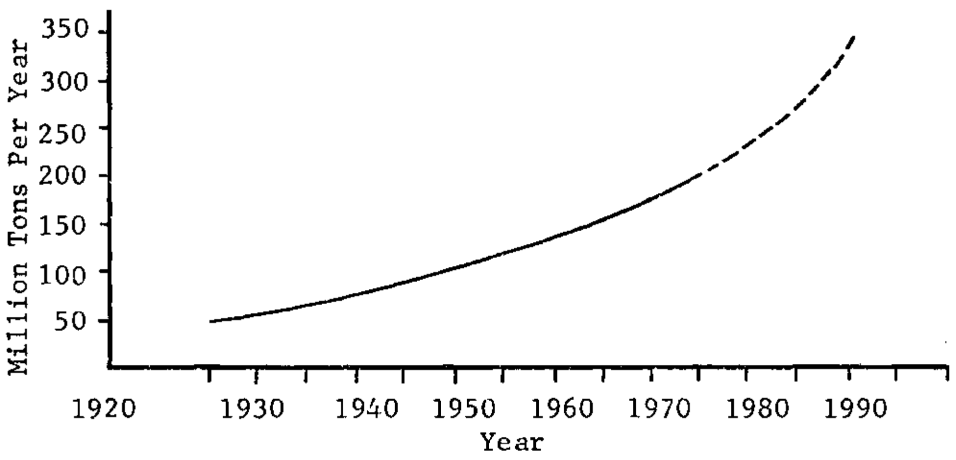


Figure 1. Total Refuse Production in the U.S.*

*Municipal and commercial sources only.

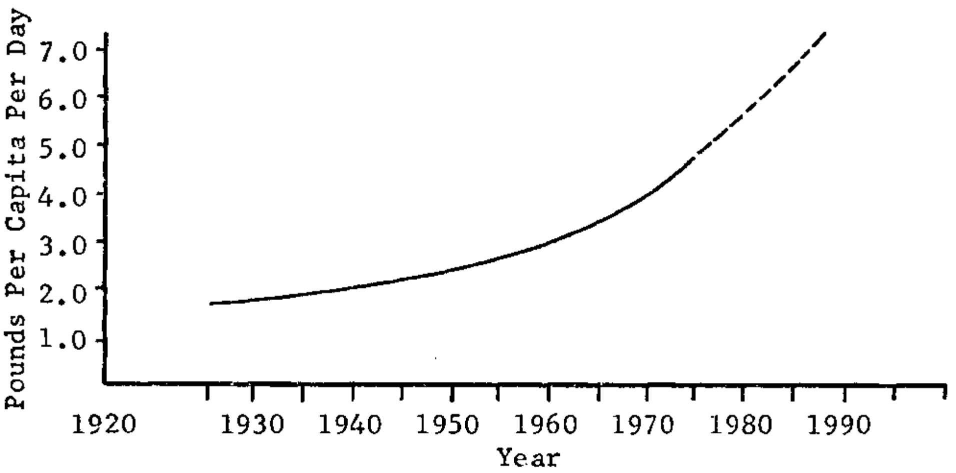


Figure 2. Per Capita Refuse Production

issues. Years of neglect and apathy have allowed the problem to reach a near critical stage, certainly a stage at which prompt and greatly increased attention and effort are sorely needed. This nation is beginning to realize that something on a higher and more effective plane must be done to dispose of our solid waste. We are fast running out of holes to fill up and dead end roads to clutter. Large metropolitan areas have run out of acreage for sanitary land fills and are faced with the prospect of hauling their solid wastes hundreds of miles to isolated areas at a greatly increased cost or to find other methods of disposal.

The total solid waste load generated from municipal, commercial, and industrial sources in the United States amounts to more than 360 million tons annually. Agricultural wastes add an additional two billion and mineral solid wastes generated is just over one billion tons (2). Altogether, over three and one half billion tons of solid wastes are generated in the United States every year and this figure continues to climb. The safe and economic processing and disposal of such vast quantities of solid waste material pose enormous problems and will require equally enormous expenditures of monies. The traditional means for coping with solid wastes -- the refuse can, the garbage truck, and the open dump -- are no longer satisfactory enough.

Solid waste disposal is already a big business and promises to become larger. The storage, collection, and disposal of solid wastes is one of the major economic expenditures of local governments. Two and one half billion dollars is estimated as the current annual public cost of solid waste collection, processing, and disposal (3). This figure will increase as less than half of the cities and towns dispose of community refuse by approved sanitary and nuisance-free methods and large expenditures will be required to bring these communities in line with acceptable standards (4).

Decision making in solid waste management has become more difficult and complex. The public is more interested in the proper disposal of waste and hence exerts more pressure on the decision maker. More methods of disposal are being developed; therefore, the choice of alternatives has enlarged. Wastes are beginning to be properly disposed of, resulting in an increase in disposal costs. Laws and regulations are being drawn up that restrict the disposal system and require more attention from the personnel associated with the system. Primary responsibility for solid waste collection, processing, and disposal has traditionally rested with the local levels of government, with state agencies involved in regulatory activity. The burden of decision of the method of disposal to be used in a local area falls upon the personnel of the local governmental decision making body. In most cases this is either the local city council or county board of commissioners. These men normally are unskilled in the area of decision analysis and often perform their duties on a part-time basis. They make decisions based upon intuition and the attractiveness of the presentation of a particular method of disposal. Political expediency often has a great bearing on the decision which is reached.

With the increased interest in solid waste disposal, the addition of stricter regulations, and the increase in funds (mostly federal), a better method of project selection needs to be derived. This method can assist local governments in arriving at a decision which determines the optimal balance between the various acceptance criteria.

General Nature of the Problem

Governments, unlike private industry, are not profit making organizations. Projects undertaken in the public sector have the goal of providing service to the public. While a profit motive does not exist in the public sector, there is an attempt made to maximize the benefit to the public while holding the cost to a minimum. The criteria used for the selection of investment proposals in private industry do not generally hold true in the selection of projects to be invested in by government. The criteria used in the decision process in government are multi-dimensional as the objectives to be met are also multi-dimensional. This multi-dimensionality arises as government serves many masters. Not only does it serve the general public with its wide variance of views, it also is affected by diverse pressure groups within the general public. In addition, higher and lower echelon levels of government assert pressure. Decision makers in private industry normally only have to satisfy the desires of a small group. This is not to say that decision making in private industry is simple. However, in the private sector decision makers normally have a structured decision process and an established set of analytical tools.

This multi-dimensionality of criteria makes the public decision maker's task even more difficult as often these criteria are not complementary and the satisfaction of one criterion can result in the ignoring of another. Due to the multiple goals involved, trade off relationships must be examined, and an optimal balance must be sought.

The criteria considered in the public sphere are both quantitative and qualitative. That is, it is possible to put values in the form of numbers on some of the criteria (e.g. cost of different alternatives), while it is not possible to express other criteria in a numerical sense (e.g. the measurement of public sentiment towards certain criteria). It is these qualitative criteria that add inexactness to the decision process. However, qualitative criteria are nonetheless important to an evaluation process.

Added to the complexity of the decisions facing the public decision maker is the lack of knowledge of the decision maker himself in the area of solid waste disposal. Urban land-use planners have almost universally ignored solid waste disposal as one of the necessary considerations in city planning. In the eyes of the public administrator, the political scientist, and the economist, there has been little room for such mundane concerns as the disposal of refuse. Engineers have been traditionally oriented to water pollution problems, and even the public health official receives nothing but a minimal orientation on the solid wastes problem. In fact the public officials who are making the decisions in the area of solid waste disposal have only little more knowledge on the subject area than that of the average citizen. The lack of competence is shown as the Bureau of Solid Waste Management estimates that 94 percent of existing land disposal operations and 75 percent of incineration facilities were found to be inadequate (5).

Research into the area of decision models has tended to center where the source of funds are. A considerable amount of study has been done in the private sector in the area of capital budgeting. In the private sector a multitude of selection models with different approaches exist. In the public sector, what little research into the development of decision and ranking models has been in the area of public works and research and development. Again this is where the funds are. Decision models to help local governments are few and far between. It is just in the past ten years that city planning has received the attention it needs.

The problem boils down to the fact that generally the decision makers are uneducated in the area of solid waste disposal, they have very few tools to aid them in their decision making process, and they are faced with complex and multi-dimensional selection criteria. Decision making in this environment is a difficult task to say the least.

Scope of the Study

This study is concerned with the development of a decision model which will aid in the selection of the proper method of solid waste disposal for a local government. While the central emphasis will be placed upon the development of the decision model, the study will include a review of solid waste disposal methods, and a review and critique of some decision models already in use. It is the intention of the author to hold the theoretical development to a minimum and seek a decision process that will truly aid the decision maker at the local level in arriving at an effective decision. Although the disposal of solid waste is but a part of the entire solid waste management plan, only those aspects pertaining to disposal will be considered. Any effects the disposal decision has on other aspects of the overall solid waste management plan will be pointed out and considered. This study will be centered on the urban areas where the greatest problems exist and where the need for immediate concern is centered.

Method of Approach

This research was carried out in a series of fairly distinct steps as is outlined below:

(1) The problem was identified and some facts bearing on the problem were given.

(2) A literature survey was performed to both familiarize the author on the subject area of solid waste disposal and to see what work had been done in the development of governmental decision models.

(3) A survey was conducted of current and projected disposal methods. In this survey, the advantages and disadvantages of each method were noted.

(4) The next step was to develop a selection model. In the development of this selection model, the various approaches now in use were checked for their validity in this subject area. Approaches considered were: constrained optimization models using such techniques as linear programming and dynamic programming; economic analysis models using various engineering economy techniques; risk analysis models which provide for uncertainty; the benefit-cost ratio used by the Federal government; and decision theory approaches which can handle multi-dimensional criteria which are both qualitative and quantitative in nature. The model developed follows the decision theory approach and is a multi-dimensional scoring model. In this model the criteria considered relevant were presented and a method for establishing criteria weights and ranking alternatives in

order of "worth" was devised.

(5) The criteria were examined in detail and performance measures were outlined for each factor. Measurements of each criterion were converted into common scale. Those criteria which were qualitative in nature required subjective measurement.

(6) Once the model was fully developed and explained, an example of its use was given.

(7) Finally, some conclusions and recommendations germain to the research were given to aid in the use of the model and to indicate some areas that need additional work and study.

Throughout the entire study, the goal of developing a selection model "usable" by decision makers at the local government level was kept paramount in mind.

CHAPTER II

LITERATURE SURVEY

Overall Evaluation of the Literature

A review of the literature revealed many interesting facts. Generally, published papers concerned with solid waste disposal are written in a nontechnical style and are slanted towards the layman. Many articles are written in the "lessons learned" format with the authors championing their particular solution to the disposal problem. There is a tendency for individuals involved in solid waste disposal to fall into a particular school of thought, i.e. advocates of sanitary landfill, followers of incineration, and impassioned believers of composting. The literature is normally narrow in scope, dealing with specific aspects of solid waste disposal.

Prior to the 1960's, very little was published on this subject. Occasionally an article on landfill appeared and the advocates of composting were fairly active. Before the 1960's, reports on refuse disposal and particularly the management end were quite rare. The reason for this lack of interest was undoubtedly due to the scarcity of funds to conduct research and the unglamorous subject area. The only periodicals devoted exclusively to solid waste management during this period were Compost Science (chiefly concerned with various aspects of composting) and the Refuse Removal Journal (primarily a trade journal concerned with the collection and haul aspects. It is a strong advocate of landfill and incineration).

As the time advanced in the 1960's, the number of published papers on solid waste disposal increased. Works of a general nature were less common than those of a particular nature. The papers usually dealt with a description of a particular installation or a specific communities' solution. Incineration came into the forefront, with sanitary landfill a close second, while composting declined. Reports on the management side became more numerous, the increase being directly proportional to the addition of Federal funds into research. While there were no new journals devoted exclusively to solid waste, journals whose subject area dealt with public service began to publish works in this area. The American City and Public Works have increased the number of articles published in the area of solid waste. Environmental Science and Technology and Western City are giving increased attention toward publishing works in this area. Compost Science and Refuse Removal Journal continue to be geared to solid waste management with Compost Science spreading its scope to include the salvaging and recycling of solid waste.

Probably the two biggest contributors to the increase of interest in the area of solid waste management are the Solid Waste Disposal Act of 1965 and the current ecology movement. In 1965 Congress focused on the problem of solid waste for the first time by passing the Solid Waste Disposal Act of 1965 which authorized demonstration projects of programs to dispose of solid waste and to encourage the development of new ways to deal with the problem. Most importantly, it made funds available for research which attracts the academic community. The ecology movement mobilized public interest and sentiment and added respectability and some glamour to this field. As an example of the change in attitude; a president of a private trash collection business now teaches a college course entitled "Technological Feasibility of Resource Reclamation," and he stated that five years ago it was the "junk business" (6). The pre 1960 situation of the scarcity of papers and reports on solid wastes is changing to one of abundance.

The literature of the late 1960's and into the 70's is growing more specific and concrete in its content. It is characterized by few generalizations and is beginning to deal with solutions. More usable data are becoming available; however, a great deal of the data is geared more to the engineer than to the planner and the decision maker. A shortcoming is the lack of critical works which give the other side to the papers which sell a pet process or approach. There still does not exist a journal devoted directly to the subject of solid waste disposal and the literature is scattered and difficult to find.

The entry of systems analysis and operations research techniques into the area of solid waste disposal was late coming. Presently these disciplines have barely scratched the surface with some work being done in the area of regional planning, the collection systems, and the optimal location of disposal facilities.

Solid Waste Disposal Methods

The University of California, under government contract, has completed an up-to-date and comprehensive bibliography of work already published in the solid waste disposal management area (7). This bibliography, which includes abstracts, was invaluable in guiding the literature search.

Most of the papers abstracted in this work are slanted toward the technical operation of components in the system with each author championing his particular pet method of disposal. There seems to be a tendency for personnel in the solid waste disposal field to line up in separate camps in regard to a particular disposal method. This narrow mindedness has tended to force a certain disposal decision as the first step and then a study is made to justify the decision.

The American Public Works Association's book, Municipal Refuse Disposal (8), is a good comprehensive study of all aspects of solid waste disposal including a discussion on the various disposal methods, lessons learned, and suggestions for planning. Flintoff and Millard (9) present the British view of the same subject area. The University of California has published a comprehensive study on solid waste management (10). This study used the multi-disciplined systems approach to look into a wide range of problem areas in solid waste management. Subject areas covered were the use of operations research techniques, planning and economics, public health, and technology. In the operations research phase, the objective was to explore the potential of operations research to help in the definition and solution of solid waste disposal problems. A waste generation model was developed having sub models as subordinate elements which were useful in studying a real world system.

Works published on the various methods of disposal are numerous. These reports are often technical in nature and are written in support of the particular disposal method being advocated. Some of the better works are:

1. Corey published (11) a book which includes important theoretical and practical aspects of incineration.

2. American Society of Mechanical Engineers (12), (13), (14) has a series of reports that include articles presented in the 1964, 66, 68 National Incineration Conferences.

3. Clarke, S. M. (15) wrote an article which looks into the costs of incinerators.

4. Blanke (16), Buckland (17), Kramer (18), Connell (19), Rogus (20), and Velzy (21) all published articles on the potentials in incineration to include various usages of the heat from incineration.

5. Johnson and Anderson (22) presented an economic feasibility study for a refuse and sludge composting plant.

6. The city of Atlanta (23) has published a factual report on the costs of running sanitary landfills.

7. An article was published in <u>Public Works</u> (24) which discussed refuse disposal via railroad land haul.

8. Sutin (25) presented an article advocating the pulverization of solid wastes.

9. Compton and Bawerman (26) discussed the effects the various disposal methods have on air pollution.

This list is but a sample of the numerous works published on the subject area of solid waste disposal that are oriented towards the technician.

Planning for Disposal

One of the significant parts of the Solid Waste Disposal Act of 1965 was the authorization of grants for state and interstate planning which provided for surveys of solid waste disposal practices and problems, and of developing solid and waste disposal plans for such areas. This was the mechanism by which long-range plans for solid waste disposal could be made (27). Here it was recognized that planning must be done on a comprehensive basis and that solid waste plans must be consistent with the broad needs and multi-dimensional objectives of the community and the surrounding region.

Toftner (28) presented a document, published by the Bureau of Solid Waste Management, intended to aid the various states in preparing comprehensive solid waste management plans. This document describes the basic features of the planning process. A basic planning model is presented (Figure 3) and a guide to preparation of the written plan is given. No methodology is presented for deciding among the various disposal alternatives. The use of Operations Research techniques is recommended; however, no specifics are given.

Following the guidance of the Solid Waste Disposal Act of 1965, several local governments have developed solid waste disposal plans after performing comprehensive studies of the problem in their area. The Bureau of Solid Waste Management has published several of these studies as sample plans. Morse and Roth (29) used a systems analysis approach for regional handling of solid waste disposal in the Buffalo, New York area. The entire waste disposal system was modeled and the model included all the components and displayed their interactions. This is the initial use of

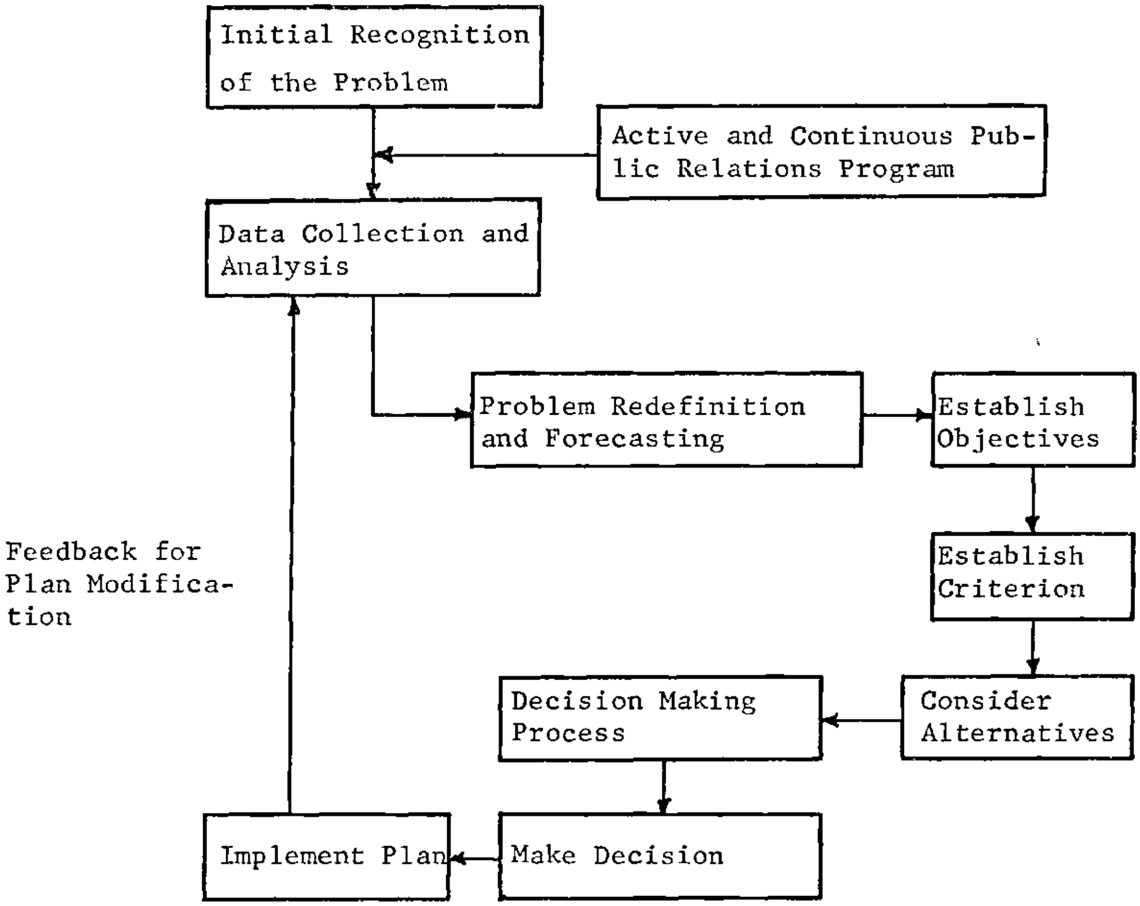


Figure 3. Basic Planning Model

systems analysis in this field, and while this effort was far from comprehensive, it can serve as a start for planners in the application of quantitative techniques for establishing more efficient solid waste systems. A facility selection model which was developed as a computer program was presented. This study provides good insight into the complex nature of the problem and points out the need for additional research.

Jones and Henry (30) also prepared a study for Oakland County, Michigan adjacent to Detroit. This was a staff study approach using no systems analysis or operation research techniques. The strange part about this study was that the method of disposal was decided in advance by some intuitive means and then the study was made to support the decision. This backwards approach seems to run contrary to any accepted planning process. No other alternative disposal methods were considered.

Thomas, Dean, and Haskins (31) prepared a study for Cascade County, Montana. This report used a standard staff study approach to the development of the plan. It does point out some of the problems encountered in a more rural environment. Various alternatives were considered and the decision was reached by the use of economic analysis. No structured decision model was used.

While the methodology used in planning for solid waste disposal has improved and more local governments are planning, no decision models are in use which aid the decision makers in arriving at solutions that maximize the "worth" of the decision to the local community.

The Resource Recovery Act of 1969 (32) is a bill which amends the Solid Waste Disposal Act of 1965 in order to provide financial assistance in the construction of solid waste disposal facilities. This act goes beyond the Act of 1965 which only allowed funds for research and development and funds to aid in the preparation of plans.

The literature, as pertains to decision making in solid waste disposal, is almost nonexistent. An article by Wolfe and Zinn (33) advocated the use of systems analysis in the solving of solid waste disposal problems. It was a vague article stressing the need for usage of the systems approach; however, it did not present any specific decision models. Klee and Garland (34) discussed the possible use of decision trees in solid waste planning as regards to what disposal alternative to consider. This article was almost a direct translation of Magree's work on decision trees as used in capital investment. This approach is of little value as the demand for disposal will remain and the amount of refuse to be disposed of is increasing at a predictable rate. This method is useful only when uncertainties are present. It also is one dimensional, as it deals only with the cost criterion. These two articles represent about all there is written on decision making directly related to solid waste disposal.

Government agencies that have research and development responsibilities have prompted research into decision models used in project selection. In this area, a large number of papers has been written which propose models for the project selection decision. One recent bibliography (35) identifies over 150 such papers. As selection of projects in R and D closely parallels the decision environment in solid waste disposal, several of these approaches have definite merit and can be modified for use in the solid waste decision environment. Both decision areas are concerned with multi-dimensional criteria and are involved with governmental decision making. The unknown is a greater factor in R and D project selection, whereas in solid waste, the decision is being made about alternative systems which are usually tried and true methods.

The models used in R and D can be classified into four categories:

1. Scoring Models, e.g. (36), (37), compute an overall project score based on ratings assigned to each alternative project scored over several criteria. Both qualitative and quantitative criteria can be handled in these models and the models are designed to operate with subjective data.

2. Economic models such as ranking on the Rate of Return, The Lorie-Savage ratio, the Solomen measure, and the Maximum Prospective Value Criterion base project rankings on economic criteria (38), (39), (40).

3. Constrained optimization models (41), (42), (43) seek to optimize some economic objective function subject to specific resource constraints.

4. Risk analysis models, which are based on a simulation analysis performed on probabilistic inputs, with the results being given in distribution form as regards effects on the specific criteria considered.

Of the four categories, the scoring model category seems to present the best approach for decision making at the local government level. This realization will be covered more in detail in Chapter IV.

Seinfeld and McBride (44) have studied the problems of optimization with multiple performance criteria. The optimization problem they considered was complex and had several noncomparable performance criteria.

A practical scheme is proposed for problems in which the criteria can be ranked in order of importance. The solution procedure involves a nonlinear programming technique. In the area of research and development, Moore and Baker have written two papers promoting the use of scoring models in the evaluation of alternatives. In the first article (45) the advantages and disadvantages of the use of the scoring models are discussed. Two main objections to the use of scoring models are: First, the scoring model is often thought of as being considerably less accurate in its ability to process data than economic analysis or mathematical approaches to project selection. Secondly, because of lack of explicit model structure and due to the rather arbitrary manner in which previous scoring models have been presented, it is nearly impossible to prescribe how to construct an acceptable model for a specific situation. The bulk of the article presents ways in which these two objections can be overcome. In the second article (46) the two authors compare three test models; a scoring model, an economic model, and a constrained optimization model. The results of the experiment suggest that scoring models compare favorably with the other two methods and are neither as restricted nor as powerless as previously believed.

A final aid to decision making used by government agencies that needs to be covered is the use of the benefit-cost ratio in determining the acceptability of projects. Several standard engineering economy textbooks, such as DeGarmo (47) and Taylor (48) provide adequate coverage on the definition and use of the benefit-cost ratio. The benefit-cost ratio is used in those agencies dealing with public works projects and transportation systems. The benefit-cost ratio has many problems and limitations when it is used and an article by Crumlish (49) covers the advantages and shortcomings of this approach.

CHAPTER III

DISPOSAL METHODS AND CHARACTERISTICS

The purpose of this chapter is to provide a general understanding of the operating characteristics, advantages, and disadvantages of various solid waste disposal methods. The coverage will be general and no attempt will be made to present a detailed, technical description of the disposal operations.

Open Pit Disposal

Open pit disposal simply involves the dumping of collected refuse in a site set aside for that purpose. It is perhaps the oldest method and is still in use by approximately 30 percent of the cities, especially those having sufficient, inexpensive land areas distant from the city proper. This method is the crudest method of disposal and is on a level with the outdoor toilet; both will meet the basic requirements in an emergency, but are not desirable as permanent facilities for a local government.

Advantages	Disadvantages
1. Inexpensive to operate.	1. Contributes to air and water pollution.
	2. Are harborages of disease vectors.
	3. Are a source of fires.
	4. Serious nuisances and health hazards result.

5. Offer unsightly conditions to the surrounding area.

6. Even the best open pit is an unsatisfactory solution.

Sanitary Landfill

Sanitary landfill is a disposal technique in which each day's collected refuse is completely covered with a layer of earth at least one foot in depth, thus eliminating most of the offensive features associated with open pit disposal. The refuse is also compacted on site, usually by a crawler tractor. Sites involving long hauls necessitate the building of transfer stations.

Advantages

1. Small initial capital investment. (Cost of submarginal land.)
2. Low operating costs.
3. Simplicity of operation.
4. Reclammation of unusable land.
5. Almost no air pollution.
6. Combined garbage and refuse collection is possible, no sorting is required, i.e., a lower collection cost.
7. Personnel requirements are minimal.
8. It is a flexible operation, capable of accepting varying inputs.

Disadvantages

1. Lack of decomposition of some items; site is active in excess of 30 years.
2. Source of water pollution, bacterial, and chemical contamination of surface and underground water systems.
3. Health hazard if not properly run.
4. Higher transport costs as sites are not usually situated close in.
5. Requires large quantities of land.
6. Operational problems may be frequent in inclement weather.
7. Undisintegrated refuse may catch on fire.
8. Fills may generate dangerous gases.
9. Close in urban land has become too valuable for disposal means.

Incineration

Incineration is the controlled burning of refuse (excluding unburnable and most construction waste) in especially designed centrally located furnaces. Burning temperatures are maintained between 1,400 and 2,000 degrees Fahrenheit to insure complete combustion. This method is not a complete disposal method, as not all refuse can be processed, and after the process is completed, the inert ash must be disposed of. The residue which has one fourth the original mass and one tenth of the original volume of the refuse, can be utilized for road surfacing or as construction fill.

Advantages

1. There is an 85-95 percent reduction in volume of refuse.
2. A sterile, inert ash is what remains.
3. The heat of combustion can be utilized to produce electricity, steam, dry sludge, and to purify sea water. This use can offset costs from 25-40 percent.
4. Site can be centrally located for economic haul.
5. Minimal nuisance from vehicles, noise, ash, odor, etc.
6. Small site required.
7. Disease vectors are held to a minimum.

Disadvantages

1. There is a high initial capital investment.
2. The operation and maintenance cost is high.
3. This method results in air pollution (principally particulates and hydrocarbons) and requires expensive air pollution control devices.
4. This is not a complete disposal method as ashes and other residue from the furnaces must be hauled to a disposal site.

Composting

Composting is a biochemical process which alters the composition of organic materials into a stable, humus-like end product. Modern composting is a rapid but partial decomposition of moist, solid organic matter by the use of microorganisms under controlled conditions. This process requires the separation of noncompostables such as glass and metals for salvage or further disposal. This process usually combines compostable refuse with sewage sludge or manure in the development of a soil enrichment end product.

Advantages

1. This method produces a usable end product which, if it can be sold, can offset disposal costs. In Europe, which incidentally utilizes composting more extensively, the cost to process one ton of raw refuse was $4.55 and the average income from sales amounts to $0.90 per ton of raw refuse for an average net cost of $3.65 which compares favorably with the cost of other methods of disposal (50). The cost offset does not account for the savings accrued by the amount of materials conserved.

2. Produces a soil enricher and offers favorable conditions for salvage of rags, glass, paper, cans, and metals.

3. Combines the process of garbage and sewage sludge disposal.

4. Hauling of refuse to site is minimized as the plant can be located close in.

Disadvantages

1. Operating costs are high (labor needed in segregation process).

2. Initial investment costs are high.

3. No steady market for the end product has been found.

4. Bad odors and possible public health problem results.

5. This is not a complete disposal solution.

5. Site for plant does not require extensive land area.

6. High conservation of materials results.

Dumping at Sea

This method was used in the past; however, due to excessive pollution of shore areas, the United States Supreme Court prohibited this method of disposal in 1933 (51). Certain items are allowed to be dumped at sea, such as ammunition and inert car bodies. Recently, new developments have arisen which open up this method of disposal. It has been suggested that car bodies and large inert waste be dumped at sea to form artificial reefs. Consideration has also been given to the possibility of compacting refuse into dense sinkable bales and dumping at sea. It has also been suggested that refuse be incinerated at sea and the inert residue be dumped.

Advantages

1. The creation of artificial reefs, thereby increasing aquatic life breeding grounds.

2. A good means to dispose of large bulky items which take up valuable land space.

Disadvantages

1. The long haul offshore to avoid pollution and to place refuse in desirable locations is expensive.

2. Variation in sea and weather conditions affects the reliability of this operation.

3. It would not be a complete method of disposal.

Feeding Food Wastes to Swine

Only garbage can be disposed of by feeding it to swine. The garbage must be separated from unedible refuse, cooked to destroy disease organisms, and fed to hogs on farms, especially built for garbage feeding.

Local governments no longer use this method; however, some private contractors still dispose of garbage by contracting with restaurants and large institutions. This practice is generally fading out of use.

Advantages

1. A source of feed.
2. May provide an additional revenue source for a local government.

Disadvantages

1. Presents a health hazard even under ideal operating conditions.
2. It is costly to cook the garbage.
3. It presents an eyesore and is a source of water pollution.
4. It is not a complete disposal process, i.e. the animal waste must be further disposed of.
5. There is a requirement for separation.

Salvage

The term salvage covers a multitude of disposal processes: the rendering of animal wastes for fats; and the sorting of refuse for metals, tin cans, glass, paper, rags, and other materials that can be resold. Salvage is most profitable when the refuse is homogeneous, as is commercial and industrial waste. When salvageable material is mixed with garbage and other refuse, reclamation becomes less profitable due to the high labor costs. This method is only a partial disposal method and is employed in conjunction with some other disposal method.

Advantages

1. Makes use of some of the refuse, i.e. the recycling conserves materials.
2. Salvage may help offset the disposal costs.

Disadvantages

1. Normally done manually, labor cost is high.
2. Health and safety of workers is endangered.

3. Success dependent on value of scrap.

4. Decreasing prices for salvage materials and increasing labor costs frequently make it uneconomical.

Dual Disposal of Garbage and Sewage

Garbage can be disposed of by on site grinding or centrally located grinders and then flushing it into sewers. Garbage is kept or collected separately from other refuse, it is ground while water is added and then flushed into the sewers. This is only a partial solution. While the end product of this process is still a solid waste, it is greatly reduced in volume. This is not a true disposal method; it is more of a transformation process. It is also employed as a side line of some other disposal method such as composting.

Advantages

1. It is a convenience to the householder.

2. Lowers the cost of transportation.

3. Uses existing sewer lines and treatment plants.

4. Best known method of treating organic waste.

5. Produces gas and composte which is salable.

6. Reduces fly and rodent population.

7. Refuse free of garbage can be picked up at longer intervals, thereby reducing transport costs.

Disadvantages

1. May require central grinder plants with high initial capital outlay.

2. It is only a partial solution.

3. May require an increase in existing facilities; larger capacity sewage treatment plants.

Other Methods

There are several other methods of disposal which are either new, untested, in the R and D stage, or have limited application. These methods may be applicable to a specific area or may have value in the future as their worth is proved. Many of these methods operate from the premise that solid waste is a resource from which valuable by-products can be derived.

Pyrolysis (R and D stage)

This is the process of heating combustible material in closed vessels devoid of air to produce combustible gases, tar, and charcoal on a continuous flow basis. Most of the products of combustion (gas, charcoal, tar) are potentially useful. This method requires separation of refuse to exclude non-combustible refuse. The pyrolysis products should all be combustible as fuels with existing technology and mimimal air pollution. At present, this method can only process small amounts of combustible refuse. Pyrolysis shows definite future potential (52).

Wet Oxidation of Organic Wastes (R and D stage)

Under this concept, certain fractions of solid wastes are subjected to special processing to produce raw materials which may then be utilized for the production of consumer goods. This process would take organic wastes found in refuse, including manures, tree trimmings, grass clippings, sewage sludge, demolished lumber, and waste paper -- apply a wet chemical oxidation process which would yield thermal energy and certain usable by-products. For example, the fractionating of wood products produces industrial chemicals and residual pulp which can be used to produce gypsum board, packaging material, and other low cost speciality items. The process of wet oxidation can be used effectively on organic materials; especially those with a high carbon content to recover potentially usable by-products and thermal energy. The end product of this process is in a form that is compact with no handling or disposal problems resulting. This process also has application in the processing of specific industrial wastes such as paper mill pulping liquors, masonite liquor, cheese plant whey, sewage sludge, and water-fuel oil dispersions. At present, a great deal of this industrial waste is dumped into rivers and streams thereby introducing great quantities of water pollution (53).

Deep Well Injection

This method of disposal invisions the disposal of solid wastes in a liquid form by injecting slurries of sewage and ground up refuse into played out oil and gas fields. Also specialized and hazardous industrial wastes could be disposed of in this manner. Due to the depth of these wells, surface pollution would not result. This method of disposal is dependent on the availability of the deep well sites. Transportation of the waste for long distances could result in prohibitive costs.

Grinding of Refuse at Sanitary Landfill Sites

This method grinds the refuse at the disposal site and the ground refuse is mixed intimately with earth prior to being placed into the sanitary landfill, thereby obtaining a uniform and compact sanitary landfill to enhance future use of the property. The grinders do represent an increased capital outlay cost; however, the process results in savings by prolonging the life of the landfill and decreasing the amount of land needed. Decomposition of the refuse is also speeded up (54).

The basic disposal methods have been surveyed. While there are ultimately only three possible disposal sinks; the land, water, and air, the numerous basic disposal methods and reduction processes can be combined to come up with a considerable number of alternative disposal systems which must be evaluated for their particular worth to a local government disposal agency. Figure 4 shows the alternative disposal systems that may be developed.

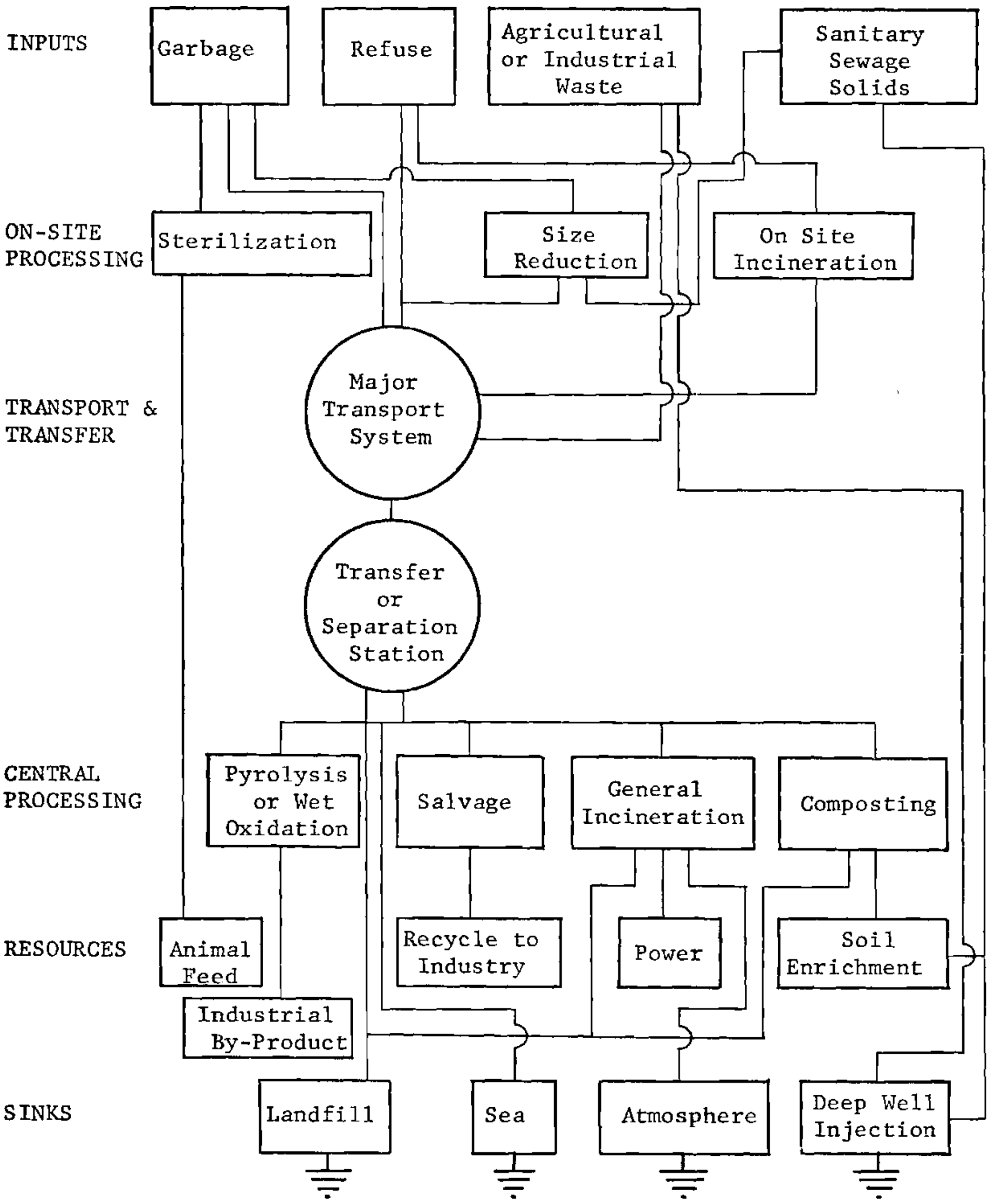


Figure 4. Possible Disposal Systems

CHAPTER IV

DEVELOPMENT OF THE DECISION MODEL

The Decision Environment

Prior to the actual development of the decision model, it seems to be quite appropriate to investigate the environment under which decisions are made. While the decision environment at the local level is in many respects similar to the environment prevailing at the Federal level, there are differences that need to be discussed.

Who is the decision maker? There is no specific answer to this question; however, the decision maker in local government tends to fall into either one of two diverse categories: either he is young, starting out in politics (and considering only a short stay at the local level), having a fairly decent education but lacking in experience; or he is older, fairly set in his ways, not too highly educated, often has a closed mind to innovative ideas, while adhering to the "common sense" approach to decision making. Dror (55), who has made an extensive study of public policy making, reinforces the above statement concerning decision makers at the local level and evaluates decision makers and civil service technicians as to their process patterns and outputs. As a group, decision makers are highly sensitive to public opinion and pressure groups, are low or medium in expertise, normally take the short or medium range points of view, are highly jealous of their prerogatives, and show low or medium consistency in their decisions. The civil service technicians who administer most of the local government agencies and act as advisors to the decision makers are moderately insensitive to public opinion and pressure groups, have a fairly high level of expertise (depending on educational background and practical experience), take medium range and sometimes longer range points of view, and show medium or high consistency in their decisions. The local government is almost void of decision makers who have managerial experience or are professional people. This is due to the part time nature of the job, the low pay, the dubious prestige, the pressures of the position, the headaches involved, and the stigma of being labeled a "politician."

The environment that the decision maker faces is exceedingly complex and subject to considerable variation. The many elements of the decision making system are interconnected by a highly developed, dynamic communications and feedback network. The decision system is nondeterministic, being partly probabilistic and partly arbitrary. Some of the elements of the system are stochastic processes, while others seem arbitrary and unpredictable by any means. The feedback loops are short, direct and the reactions to decisions are rapidly transmitted back to the decision makers. The close proximity of the decision maker to the affected public adds additional pressures to the decision maker as he knows there will be rapid accountability for his decisions. Due to this closeness, decisions are often subject to change.

Local governments have limited resources and the public makes many demands on these resources. The solid waste system is in hot competition for these resources, and there is a necessity for the chosen disposal alternative to be strongly justified as being worth the allocation of hotly contested resources. This limited resource situation often precludes the spending of money for extensive consultant research so necessary for many operations research techniques. It is almost imperative that what planning and data gathering are accomplished be performed with inhouse personnel or other governmental agencies. This restriction limits the level of sophistication that the decision model used can possess.

If the model requires extensive training of the user and a large expenditure of time and money to obtain accurate data in a usable form, most likely the model will not be used. Also, because of the importance placed by the decision maker on his prerogatives, hostility will meet the recommendation of the consultant who utilizes models and methodologies to select an alternative that does not include participation of the decision maker. Simplistic models which utilize the decision makers have a higher probability of being accepted and used.

The needs and capabilities of the decision makers must be taken into consideration in the development of the selection model. If the techniques used in the model are foreign to the decision makers and they distrust the model due to a lack of understanding, the model will undoubtedly be rejected. Models developed to display the talents and expertise of the model builder to his peers run the risk of not being relevant to the decision environment. Ackoff (56) pointed out the need to make the work of the management specialist relevant to the needs and capabilities of the decision maker. He cited a large corporation that had fifteen management specialists who had worked for ten years developing models and projects, and during this period, not one project or model was implemented. This group had independent authority and selected the projects and interpreted the needs of the organization as they saw fit. Management could rightly question the validity of retaining these specialists as they represent a costly non-productive element. The model builder must seek out the decision makers to determine their needs and their capabilities. Once the decision environment is understood by the model builder, he can then develop a meaningful and relevant model. Perhaps the overriding goal of advancing the state of the art should be reexamined to place additional emphasis on the goal of selling the art to the decision maker.

Possible Approaches

There are a large number of approaches that may be taken in decision making; however, these approaches fall into three classes. The first of these classes is the extrarational method which is practiced by a goodly number of decision makers. Under this method, there is no systematic set of criteria and standard methodology for evaluating alternatives. Hunches and intuitive judgments are the vehicles used to arrive at decisions. Planning is held to an absolute minimum. The advocates of this method regard the normative decision making models as a waste of time and resources, being idle daydreaming at best, and as some sort of subversive activity at worst. This method relies heavily on the experience of the practioner.

The second class is the rational planning method which uses a systematic process for arriving at a decision. The model for this method was presented in Chapter II, Figure 3. This method stresses a broad systematic planning process of a dynamic and continuous nature. This method develops a set of alternatives, investigates the alternatives for their merits and shortcomings, and then the information gathered is utilized by the decision maker in arriving at a decision. There is no formal decision model used in this method. The decision is made based upon the available information and the reasoning of the decision makers. This class represents an improvement over the extrarational class because of the systematic planning procedure and the broadening of the scope of the study. The actual decision step is substantially the same as the extrarational class, that being a subjective value judgment decision.

The third class is the use of normative models for decision making. In the use of these models the rational planning method is followed; however, at the decision stage a selection model is included to evaluate the candidate alternatives and select an optimal alternative. These normative models add to the rational planning method, as they present methodology for arriving at logical decisions. The use of the normative models requires modification of the rational planning method, in that information required for the model is normally increased and may be in a different form.

The normative models may be further classified into four categories:

1. Scoring models, which compute an overall alternative score and result in the ranking of alternatives based upon ratings assigned to each alternative for each decision criterion used. These models can accommodate both qualitative and quantitative criteria.

2. Economic models that base ratings on economic criteria such as present worth and rate of return. The benefit-cost ratio model is a form of an economic model presently used by several Federal government agencies.

3. Constrained optimization models, which use quantitative criteria and which seek to optimize an economic objective, function subject to some resources constraint.

4. Risk analysis models, which either use simulation techniques employing probalistic inputs and providing output distributions on certain criteria or employ decision tree analysis which takes into account future uncertainty and the economic consequences of each alternative.

The categories have been presented in order of increasing data requirements. The analytical power of these categories generally increases as one progresses from scoring models, to economic models, to constrained optimization models, to risk analysis models; however, this gain is offset by increasing complexity and cost, and the requirement for more accurate data.

Now that the various classes of decision making methods have been presented, a discussion of several possible decision models which can be used in selecting a solid waste disposal alternative is now in order. It is assumed that these decision models will be used in conjunction with the rational systematic planning process.

Benefit-Cost Ratio

This method of project selection is used by the Federal government mainly in the areas of public works and transportation. The benefit-cost ratio is obtained from the following simple formula:

$$\text{Benefit-Cost Ratio} = \frac{\text{Present Worth of Benefits}}{\text{Present Worth of Costs}}$$

The benefits cover all advantages, minus disadvantages to the user. The costs mean all disbursements, minus any savings that may be incurred by the government. The Federal government normally requires that the benefit-cost ratio be greater than unity to qualify as a candidate for selection. This method represents a selection process that is open to considerable manipulation by the user and in practice is often a less than satisfactory decision process as the following comments on the present state of usage indicate.

Negative side

1. Data deficiencies limit the ability to make informed choices among alternatives. The data available greatly influence the outcome of the process.

2. The greatest conceptual problem is the proper identification and adequate measurement of social benefits and costs.

3. Very little research has been done to weigh benefits and costs on a comprehensive scale.

4. Benefit-cost analyses are less useful where uncertainties are great or where qualitative criteria are highly significant.

5. There are no clear cut rules for determining the list of actions that should be considered or the scope of the systems into which the actions should fit.

6. The literature now available for guidance in studying the socio-economic consequences of government projects has many significant gaps. Theoretical economists dismiss virtually all government project impact literature published so far as being basically inadequate.

7. There appears to be no definite, explicitly formulated set of criteria for judging capital projects in the public sector.

Positive side

1. Benefit-cost analysis can provide an appropriate framework for decision makers to use in organizing the evidence and clarifying their thoughts and intuitions regarding alternatives.

2. Benefit-cost analysis should not be depreciated on the grounds of fallibility; its purpose is to lead to more informed judgments than would otherwise be possible (57).

Constrained Optimization Models

In the private sector, constrained optimization models have been used to select investment proposals. The intent of these models is to satisfy economic criteria by maximizing the profit of the firm. In the public sector, these types of models have also been used in the research and development area. However, the single criterion of profit maximization does not exist in the public sector. Rather, the objectives and their corresponding criteria are multi-dimensional with the paramount criteria varying by locality and the particular decision situation being faced. It is not sufficient to optimize just one criterion as this will result in adverse reactions respective to other criteria. The following example illustrates this point. This example is concerned with two criteria, those of the cost of pollution control and protection of public health. Let us say in this example we are evaluating the alternative disposal method of incineration.

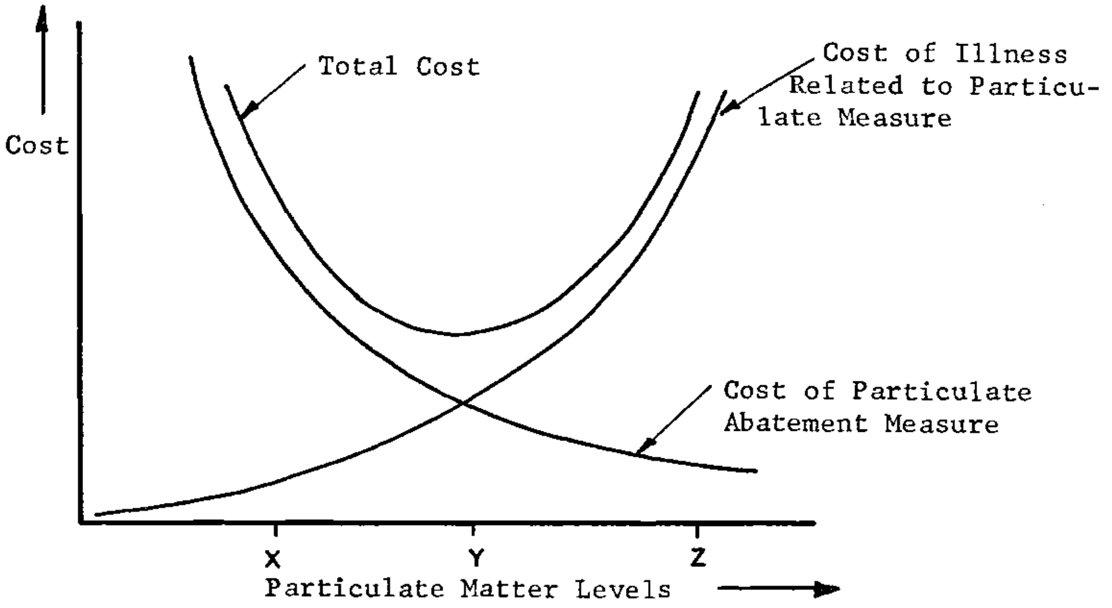


Figure 5. Example of Cost Effects of Two Criteria

If our objective was to minimize cost and public health is not considered as a criterion, the decision maker and the model would be looking at Figure 5 at the area above segment X-Y where the cost is the lowest. However, if the criterion of public health is added, the area of interest shifts to the area from segment Y to Z and the cost is increased. The more criteria considered, the more difficult it becomes to use constrained optimization models. The model becomes more complex and goes beyond the state of the present art in mathematical programming as the model is required to optimize in an increasing number of dimensions.

Even if the present solution techniques would allow optimization in several dimensions, some pertinent criteria are difficult to quantify. For example, it is difficult to put a cost figure on the air pollution effects from an incinerator or the water pollution effects from a sanitary landfill. Research into the costing of pollution effects has been extremely sketchy and better methodology for obtaining accurate cost data is needed. If qualitative criteria exist, there is a requirement to convert all measurements and data pertinent to each criterion into a common unit of measure. This unit of measure would probably be dollars. It is indeed a difficult problem to put a dollar figure on a death attributed to a disease originating from an improperly operated sanitary landfill.

In theory, constrained optimization models perform with great precision and are logically sound. However, in real life applications, accurate estimates of parameters are difficult to obtain. Consequently, without accurate data, these models can turn out to be interesting academic exercises with little relevancy to the real world situation being modeled. Given the most sophisticated, mathematically correct model and insert data that are questionable, the value of the model as a selection device is compromised. In fact, because of the prestige placed on the value of strong mathematical logic, the results may be accepted even though the model consistently selects an incorrect decision. The results may be true but not valid.

Economic Models

Since economic models base alternative ranking on economic criteria, noneconomic criteria are not handled by these models. While it can probably be easily substantiated that, in most situations, economic criteria are most important, noneconomic criteria cannot be ignored. Take for an example a situation where economic criteria were the sole criteria used in selecting a solid waste disposal alternative. The model will select the most attractive alternative that optimizes the economic criteria. The decision makers approve this optimal alternative and a referendum is taken to approve the floating of bond issues. The referendum is defeated as the public dislikes the alternative. Here the noneconomic criterion of public sentiment was ignored, and as a result the decision was invalidated. A model that could have incorporated the public sentiment criterion could have saved the decision makers the embarrassment of having a decision overruled.

Risk Analysis Models

Risk analysis models, especially those requiring simulation techniques, are very costly to construct and validate. The cost of the study may prohibit the use of these models. Models which can obtain similar results at a lower cost will normally find more favor at the local government level. However, the use of simulation should not be ruled out solely on the basis of its increased cost, as its application may result in savings that far exceed the cost of applying the technique.

Scoring Models

Scoring models come under the heading of decision theory. Scoring models rate alternatives with respect to a number of evaluation criteria. An overall score is computed and used to rank the alternatives in order of their worth. Scoring models are sensitive to decisions made during the evaluation process.

Proven operations research techniques are plentiful, but operations research professionals and usable models, particularly those effective in implementation, are scarce. It is one thing to build a model, it is another thing to use it in practice. Emphasis on the application of well developed techniques to areas of high potential payoff would greatly accelerate operations research progress. Managers look for results and are often reluctant to experiment with new methods. The closer the model is to the decision makers' normal way of doing business, the better the chance of acceptance and use by the decision maker. In regard to new innovations, the decision maker must crawl before he walks. Actual accomplishment in terms of new decision making practices is modest and management's acceptance and understanding of the operations research approach to problem solving are growing at a slow rate (58). Keeping these comments in mind, scoring models will now be investigated.

Scoring models have been in existence for a number of years; however, most research and published literature have virtually ignored the use of scoring models in the evaluation of alternative proposals. This is somewhat surprising in that scoring models have some inherent advantages over other types of models. For example, scoring models are the only models that can incorporate qualitative criteria and effectively utilize these criteria in arriving at a decision. The theory behind scoring models is fairly simple, which allows the layman to utilize these models after a short period of training. (It might be the inelegance and simplicity of scoring models that discourages knowledgeable operations research personnel.) Yet, it is these simple techniques that are most widely used in the real world, i.e. PERT, CPM, linear programming. Scoring models can utilize input data that are in the form of subjective estimates provided by knowledgeable experts in specific fields applicable to the criteria being evaluated.

Scoring models also have an advantage in that the layman decision makers can take an active part in working the model, thereby imparting the feeling of a mutual and group possession towards the decision and possibly precluding dissention with the decision at a later date. The scoring model broadens the decision base as it marries up the expertise of technicians with the political knowledge of decision makers. For example, if public health happens to be one of the criteria involved, public health experts can be called in to give advice and furnish data applicable to the public health aspects of the alternatives being considered.

Scoring models also offer increased diagnostic properties, as the weak points of specific alternatives can be graphically seen. The model presents a profile whereby the value of each alternative is shown for each criterion. Unusually low value ratings for specific criterion are borne out.

Scoring models also allow the decision maker to predetermine the impact of every criterion he considers in arriving at a decision. Criteria are assigned weights corresponding to individual utilities and, by a weighted average process, a group utility is determined for each criterion. Conflicting and inconsistent objectives can be incorporated into the model.

Another advantage of scoring models is their ability to use simple, low cost methods of data acquisition. Where the uncertainty associated with an alternative does not permit an accurate and meaningful point estimate of performance to be made, interval estimates not only are satisfactory but give a true picture of the accuracy of the data being used.

A Multiple Criteria Scoring Model

Better decision making arises through better and more complete information and by performing more exacting analysis during the decision process. In some cases, the information and data worked with can be ambiguous, but their basic role is the reduction of ambiguity and, hence, they contribute decidedly in a mathematical sense, i.e. logic and mathematical methodology replace intuition and hunch making.

The decision model that is about to be developed is a multiple criteria scoring model that can be used to assist the decision maker at the local government level in deciding on the alternative disposal method that is best for the region served by the decision body. This scoring model employs a simple systematic procedure, which utilizes both objective and subjective criteria in arriving at an optimal decision. The procedure broadens the scope of the study, in that the relevant criteria selected require additional information and analysis. The talents of the decision makers and the civil servant technicians are incorporated into the decision process. A block diagram that illustrates the steps to be taken in the use of this decision model is shown in Figure 6.

Step 1

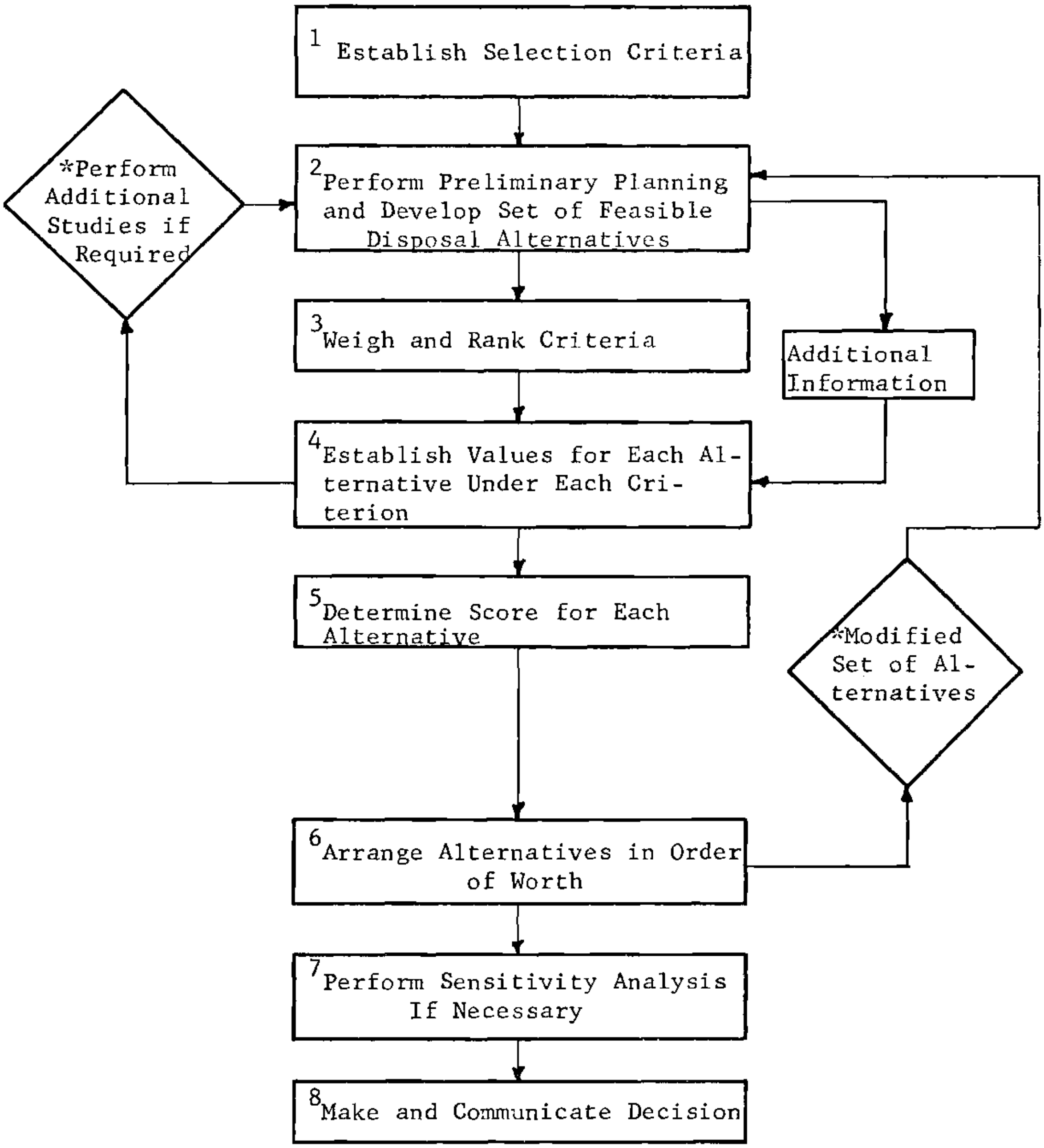
The first step in the algorithm will be to determine the applicable criteria. This is not an easy step even though it might appear to be. In the opinion of psychologists and economists, the conversion of objectives into criteria is one of the trickiest problems in the rational preparation for decision and/or action (59). The appropriate personnel of the sanitary department, in conjunction with the decision makers, should develop a list of criteria. A sample list of criteria should include the following: cost, public health protection, prevention of environmental pollution, public sentiment and acceptance, conservation of resources, implementation considerations, and reliability.

Step 2

It is assumed that a rational planning process will be followed prior to the decision phase. What data are needed to evaluate the alternatives under the specified criterion will be gathered and prepared in the proper form. The following preliminary planning studies will probably be performed:

a. A disposal practices survey should be made to determine a set of technically feasible alternatives. The existing disposal systems should be considered in the study.

b. Studies should be made into the quantities of refuse being produced. Future refuse production volumes should be projected based on



*Step taken only if situation warrants.

An example of the model's usage can be found in Appendix B.

Figure 6. Algorithm of the Scoring Model

past refuse production data and anticipated trends in the future. All solid wastes must be considered, including demolition, industrial, and agricultural wastes.

c. Once the list of alternatives is determined, a complete economic analysis should be made on each alternative. Included in the study should be the prediction of capital and operating expenditures required during each year of the disposal facility's life. Care must be taken to include all relevant costs and income. Capital costs will include the cost of the disposal site, the cost of constructing the disposal facility, any access roads and the cost of any supporting equipment. Operating costs include the cost of the actual disposal operation, plus the cost of transporting the refuse from the collection route terminal to the disposal site. Transportation costs must be considered, as restrictions placed on the location of specific disposal methods greatly affect the overall cost of the disposal system. For example, long range hauls to distant disposal sites can greatly increase the cost of this disposal method.

d. Additionally, studies of a technical nature should be made that furnish information necessary to evaluate the alternatives under the chosen criteria. A site survey should be conducted to identify sites which are available and suitable for refuse disposal facilities. A land use study should be made around potential disposal sites to determine the effect that any adverse features of the disposal operations might have on surrounding land uses. Here, environment pollution and public health experts could be called in to assist in determining the effects. If sanitary landfill is included in an alternative, a geological survey should be made to permit evaluation of the ease of evacuation, the risk of water pollution, and the probability of lateral gas movement. Transportation studies should be made to determine what effect the alternatives will have on existing roads.

e. Opinion surveys should be taken to obtain the public's views on the various disposal methods. A review should also be made of all pertinent laws and ordinances to insure that established standards are met by the alternatives.

f. Additionally, any studies deemed necessary should be made to provide information as is required by the decision maker.

Step 3

After the preliminary planning has been performed and a set of feasible alternatives have been established, the criteria are weighed and ranked in order of importance. The decision makers under the guidance of the technicians weigh and rank the criteria. Each decision maker will rank and weigh the criteria separately and then a composite weight for the entire decision body will be obtained. The criteria are presented next to a continuous scale marked off in units from zero to ten. The decision makers are then asked to draw a line from each criterion to any appropriate point on the scale. The decision maker is permitted to select points between numbers or assign more than one criterion to a single position on the scale. This exercise reflects the value the decision maker places on the selected criteria. Figure 7 illustrates how criteria weighing and ranking are accomplished.

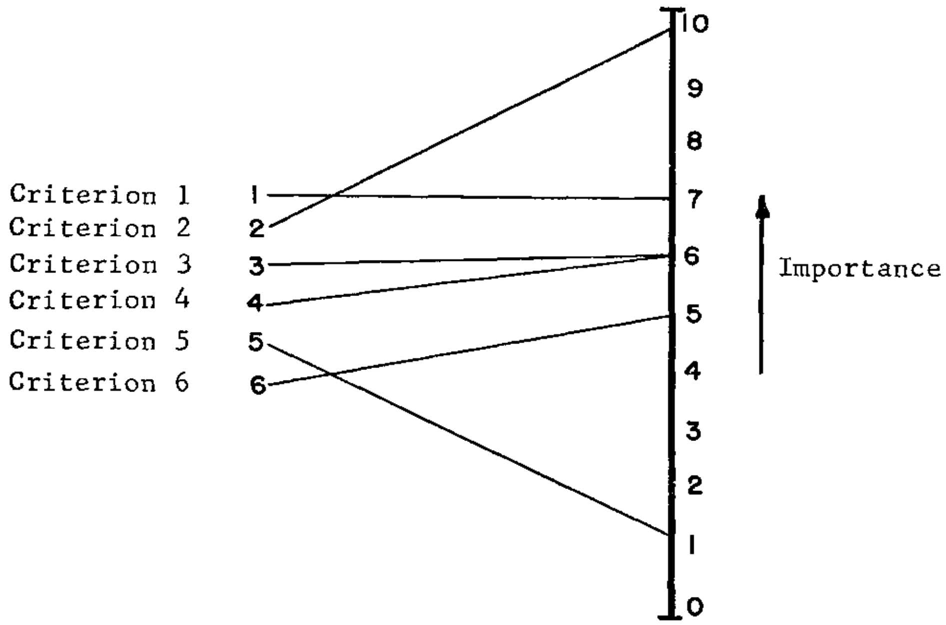


Figure 7. Illustration of Ranking and Weighting of Criteria

The raw rating assigned by each decision maker to each criterion against the scale of zero to ten (ten being the most valuable or important) is read off to two significant figures and treated as follows to determine a composite weighing of the criterion:

$$W_{cd} = \frac{P_{cd}}{\sum_{c=1}^{m} P_{cd}}$$

where

W_{cd} = weight computed for criterion c from the rating given by decision maker d

P_{cd} = rating given by decision maker d to criterion c

W_c = composite weight of criterion c across all decision makers

$0 \leq W_c \leq 10 \qquad \Sigma W_c = 10$

m = number of criteria

n = number of decision makers

A = scaling factor (A = 10).

To determine W_c, which is the composite weight of a criterion, the following formula is used (60).

$$W_c = A \frac{\sum_{d=1}^{n} W_{cd}}{\sum_{d=1}^{n} \sum_{c=1}^{m} W_{cd}}$$

When all criteria are weighed, the resulting weights are lined up from left to right in descending order of weight and placed in the first row of the decision matrix.

Row 1 W Max . . W_c . . W Min

Step 4

The next step is to take each feasible disposal alternative and establish for each alternative a set of values V_c for each criterion. Each alternative will be evaluated under all the criteria to obtain a value profile for each alternative. This value profile indicates how well each alternative satisfies all the criteria. The method used will be to select each criterion in turn and value all alternatives as to how well the alternatives satisfy the criteria. Some of the criteria are quantifiable and the alternatives can be valued objectively. Other criteria are quality criteria and will require subjective evaluations. Chapter V will go into greater detail as to how the evaluation of alternatives under specific criteria can be accomplished. Each alternative is rated on a scale of one to five to determine its satisfaction of each criterion (five represents the highest satisfaction of the criterion). These values are then added into the decision matrix in successive rows as shown in Figure 8.

Step 5

When all the alternatives are valued, a composite score is determined for each alternative and placed in the right hand column of the matrix. The score S_k is obtained by multiplying the value V_{kc} by the criteria weight W_c and summing up over all criteria.

$$S_k = \sum_{c=1}^{n} W_c V_{kc}$$

This score is a measure of the relative worth of the alternative. The resulting number is dimensionless and not endowed with a well-defined meaning such as cost, rather it is a measure of group utility.

Step 6

The alternatives are then arranged in order of worth based upon the compositive score obtained. This ordering will indicate to the decision body the relative importance of the chosen alternatives and will allow judgments as to how much better certain alternatives are over other alternatives. The alternative that has the highest score maximizes the

	Criterion 1	Criterion 2	Criterion 3		Criterion c		Criterion n	Score
Weight of Criteria	W_1	W_2	W_3	. . . .	W_c	. . . .	W_n	
Alternative 1	V_{11}	V_{12}	V_{13}	. . . .	V_{1c}	. . . .	V_{1n}	S_1
Alternative 2	V_{21}	V_{22}	V_{23}	. . . .	V_{2c}	. . . .	V_{2n}	S_2
Alternative 3	V_{31}	V_{32}	V_{33}	. . . .	V_{3c}	. . . .	V_{3n}	S_3
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$
Alternative k	V_{k1}	V_{k2}	V_{k3}	. . . .	V_{kc}	. . . .	V_{kn}	S_k
$\vdots$	$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	$\vdots$
Alternative Z	V_{z1}	V_{z2}	V_{z3}	. . . .	V_{zc}	. . . .	V_{zn}	S_z

Figure 8. Decision Matrix

satisfaction relative to the chosen criteria.

The value profiles in the decision matrix can be presented graphically for use by the decision body and for public information purposes when the appropriate time presents itself. The information provided by these profiles and the scores of the alternatives obtained by the use of carefully weighed criteria appreciably increase the knowledge of the decision maker. Figure 9 shows a sample value profile.

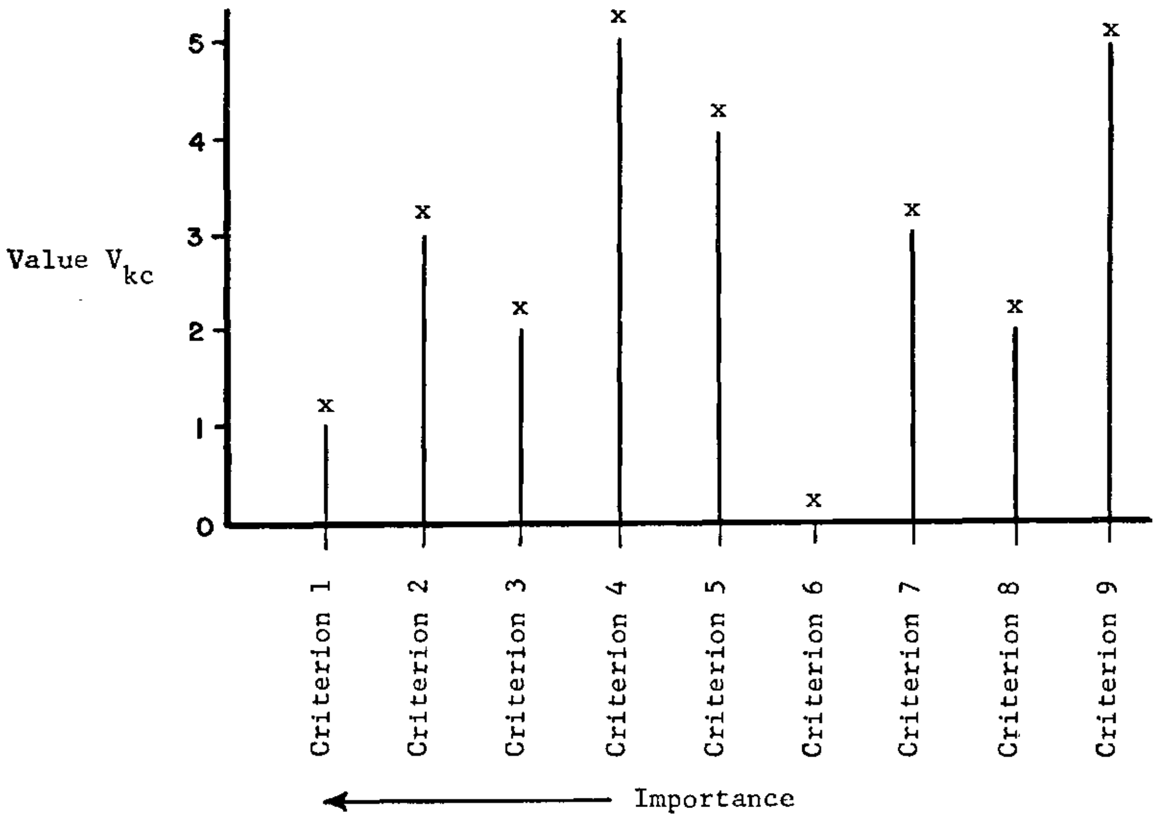


Figure 9. A Value Profile

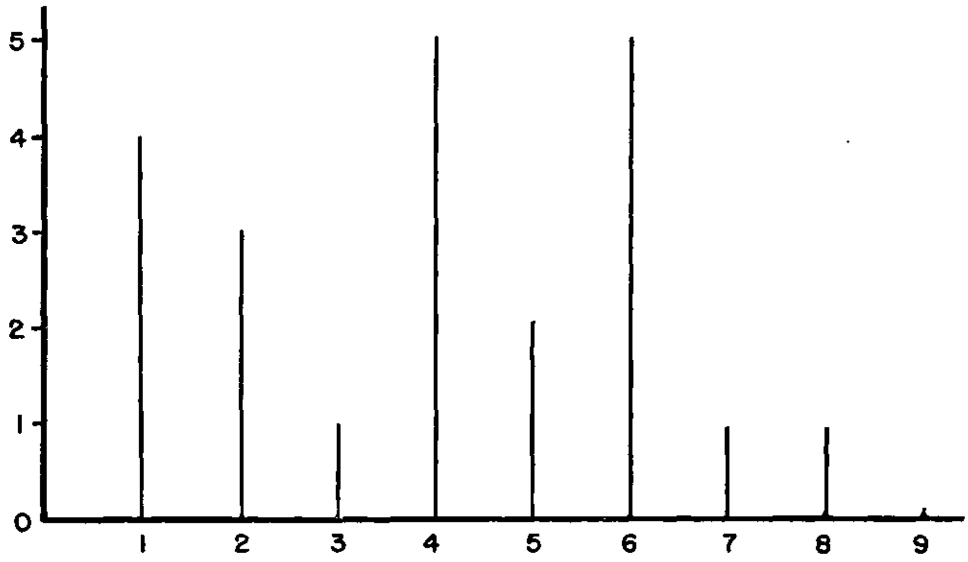
The examination of the value profiles might also provide feedback information on the set of disposal alternatives being examined. If a particular alternative scores high in all criteria except one or two, and the alternative looks promising, it may be possible to modify the alternative by adding a process which will raise the value of the low criteria. In this way, the set of alternatives being considered can be improved. The modified set of alternatives would again be put through the scoring process. This ability of the model to restructure the set of alternatives is definately an advantage. The original set of alternatives was an arbitrary list and may be incomplete.

Step 7

If deemed necessary by the decision makers, a sensitivity analysis can be performed on the decision matrix. One form of sensitivity analysis involves the changing in weighing and ranking of specified criteria to see if the final scores are changed and hence the relative worth of the alternatives. When the criteria are reweighed, a new decision matrix is made and the final score is recomputed. There should be no change in the values given to the alternatives under the criteria so the amount of computation will be minimal. Sensitivity analysis can be used to see if the final ranking of alternatives varies if the criteria weights are changed. An alternative that retains a high score even under several changes in criteria weighing represents a strong disposal alternative with considerable group utility.

Additional sensitivity analysis can be performed on the value profiles obtained for each alternative. Value profiles can be compared with each other by taking two profiles and subtracting one profile from another to obtain a difference profile. The difference profile graphically portrays the advantage of one alternative over another. Figure 10 illustrates

Profile Alt. A



Profile Alt. B

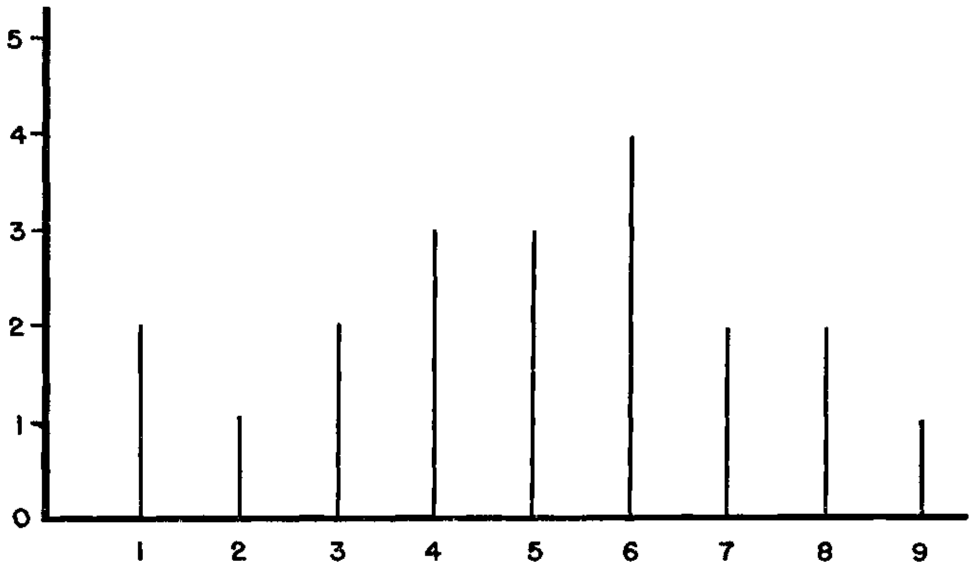


Figure 10. Difference Profile

Difference Profile A - B

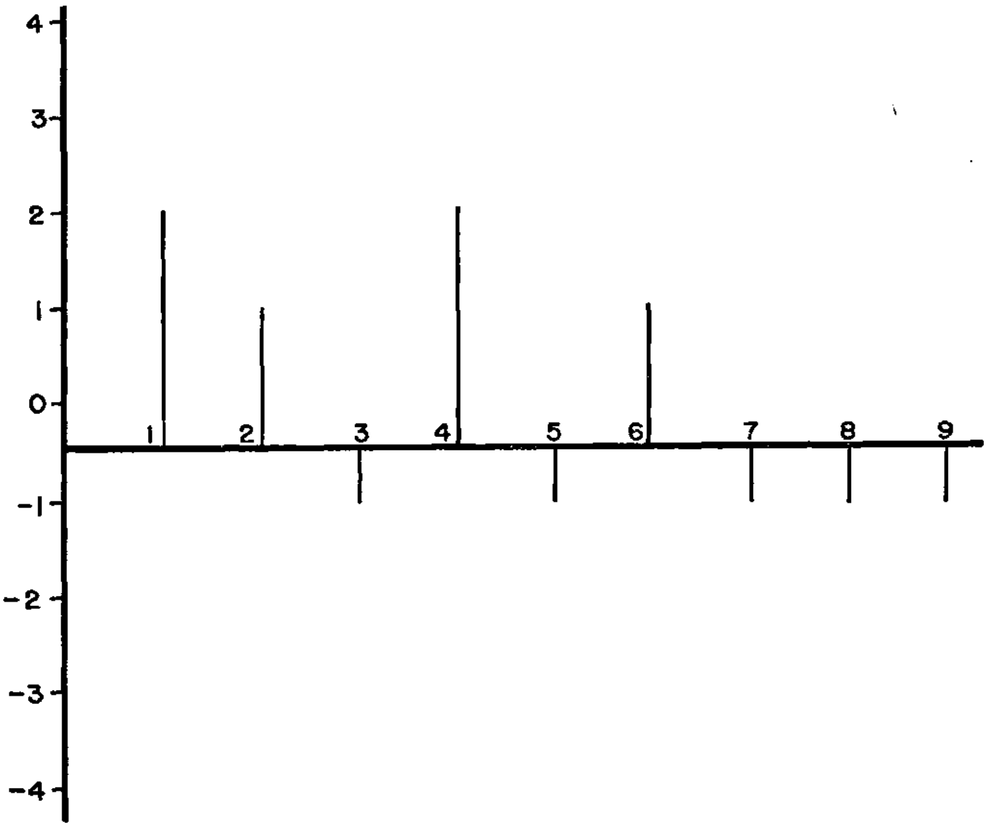


Figure 10. Continued

an example of a difference profile.

The positive values in the difference profile indicate the relative advantage that the first alternative A have over the second alternative B.

Difference profile analysis would not have to be performed on all the alternatives. It would be performed on the highest scoring alternatives. The exact number of alternatives to be considered would depend on the closeness of the scores. The first step would be to plot the top scoring alternatives on a graph comparing the values V_k for each top scoring alternative with the criteria. Figure 11 illustrates an example of this procedure. From this figure, the number of alternatives which will be candidates for further analysis will be determined. Those alternatives which dominate (higher V_k values for all criteria) can be compared by examining their differences.

If n alternatives are determined, $\frac{(n-1)(n)}{2}$, difference profiles will be made. For example, alternatives A, B, and C dominate alternative D in Figure 11 and further analysis of alternative D will not be performed. These difference profiles will give additional information to the decision makers and enable them to differentiate between the top scoring alternatives.

By the use of sensitivity analysis, the decision makers can evaluate the model and the data used in the model. It might turn out after the composite scores are obtained that the decision makers may not be satisfied with the alternative which has the highest score and they may want to select a compromise alternative. Sensitivity analysis can aid in

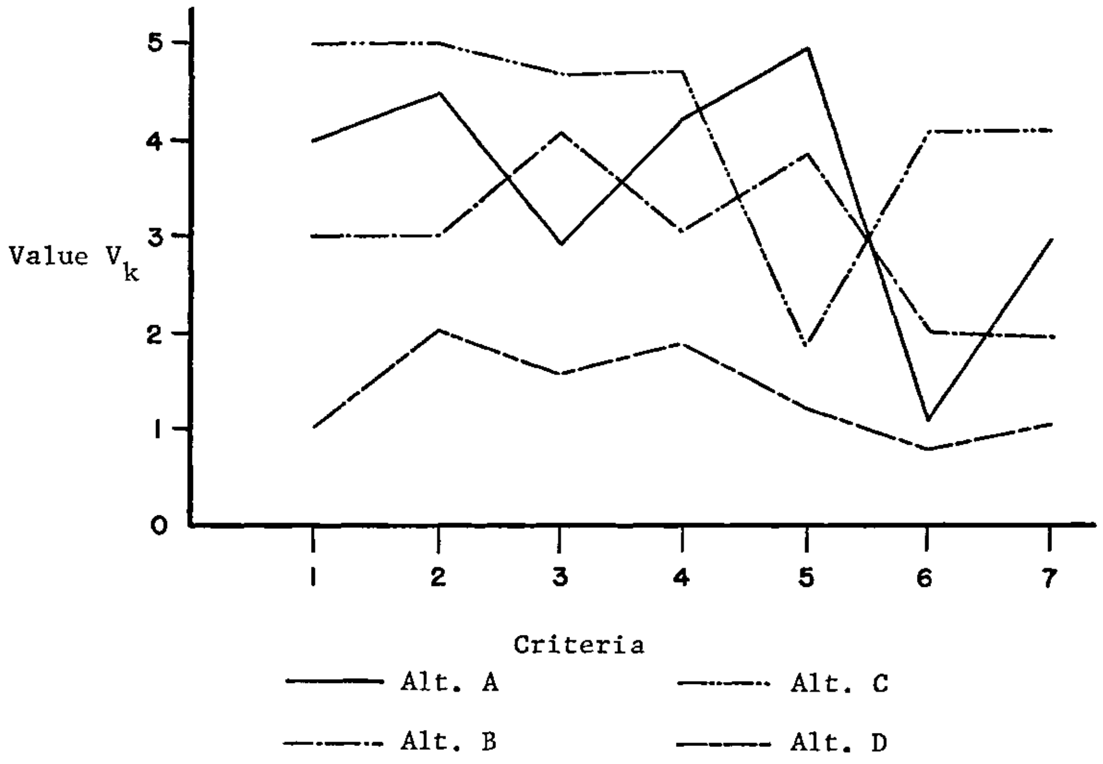


Figure 11. Alternative Dominance Graph

the selection of a compromise alternative. To the layman it would seem that the model has already selected the alternative which maximizes the "worth" and that this alternative should be chosen. It is however a fact of life that expediency and compromise are a part of politics and sensitivity analysis may have to be performed.

Step 8

The final step is to make the decision by choosing from the alternatives and to communicate the decision to the public in the form of an operational solid waste management plan. In most cases, the choice will be the alternative that has the highest score. If the final choice differs from the highest score determined by the model, the model still has value as it has generated a wide range of information to the decision makers. The model has forced the decision maker to broaden the scope of the study and to follow a set, rational pattern in researching for data that are used by the model.

It has been pointed out by critics (61)(62) of the use of scoring models that the achievement of a single score for an alternative is undesirable. Their argument is that too much aggregation submerges pertinent information. It masks and covers the true difference among alternatives and leaves no way to identify and contract these differences in decision making. To a certain degree, this comment can be relevant. If the data that go into the decision matrix are not presented to the decision makers and only the final scores are presented, pertinent information is submerged. However, if the decision maker is provided with all the information that is used to determine the score and if he takes part in the evaluation process, pertinent information will not be submerged. The use of a scoring model is recommended as it furnishes to the decision makers a logical procedure for evaluating alternatives utilizing a number of criteria. If the information is presented to the decision makers in the form of value profiles or difference profiles, they must still combine all the factors to reach a decision. Then the final aggregation is often accomplished in a less analytical fashion.

When the decision is communicated to the public, the information gathered in the study and the analysis performed by the model can be used to inform the public on the worth of the chosen alternative. The decision will be strongly supported by the logical procedure followed in arriving at the decision.

CHAPTER V

DISCUSSION OF CRITERIA

The criteria listed in Chapter IV are considered by the author to be pertinent and relevant to evaluating solid waste disposal alternatives. The mentioned criteria constitute a recommended list and can be altered by the decision makers as they see fit. In determining the criteria applicable to the local decision environment, the decision makers should give careful attention to the goals and existing directives as well as any stated objectives of the local government body.

The criteria selected should be complete, relevant, measurable, and mutually exclusive. The criteria list should be complete to insure that no important evaluation factors are overlooked in the analysis. At the same time, the criteria selected must be relevant to the decision environment. Factors of minor importance should not be included, as each criterion requires additional data to be collected and processed. Each criterion should be measurable, in that a method and a scale for obtaining a measure of performance must exist. The particular measure can be subjective or it may be objective. Criteria overlap or partial duplication should be minimized, as this increases the difficulty of interpreting the overall effectiveness of the alternatives. Mutually exclusive criteria facilitate the understanding of tradeoffs established during sensitivity analysis. One criterion should not include another to avoid improper weighting of the importance of a particular factor (63).

When the criteria have been selected, performance measures for each criterion must be derived. This is not an easy or well defined task as some criteria are easily quantified while others are qualitative in nature and have no associated quantitative measure. Qualitative criteria require subjective judgments. A popular unit of measure, easily understood by all, is the dollar. Certain criteria can be easily expressed in dollar values. Other criteria cannot be easily expressed in terms of dollar value.

For objective criteria, measurement schemes are readily apparent. However, for subjective criteria, rating schemes must be devised which give accurate evaluations of the alternatives. The use of rating schemes is not objectionable. However, the ranking procedure must be reliable, accurate, and represent a meaningful measure of the alternative's performance under the subjective criterion. For subjective criteria, knowledgeable individuals will be used to evaluate the alternatives. Subjective ratings by knowledgeable personnel is a feasible course of action as the expertise is often available. The use of subjective criteria should not be downgraded or discarded. Some factors bearing on the decision can only be subjectively measured and to disregard these factors may contribute to a wrong decision being made.

The criteria suggested in Chapter IV will now be described in detail. A detailed discussion of each criterion will be made, a measure of performance will be determined, and a measurement scheme for evaluating the set of alternatives under each criterion will be derived.

Cost

Cost will always be an important criterion at the local government level where monetary resources are scarce. There are many competing demands for the funds that are available. The competing demands are represented by the various services the local government provides such as police protection, education of children, health and welfare of the citizens, and maintenance of roads and grounds just to mention a few.

The selected performance measure for the cost criterion will be the annual cost of disposal. This will include all costs required to collect, transport, and dispose of the refuse. It should also include any offsetting income that might be derived. The cost of collection and transport must be included, as a particular disposal alternative can have a definite influence on the transport and collection cost. For example, the haul distance is an important economic factor for the sanitary landfill alternative. Remote locations will greatly increase the transport costs and hence the total cost. Many disposal systems are selected by considering only the cost of disposal and not the total cost. This approach is faulty as the cost of disposal is not independent of the transport and collection costs.

In determining the annual cost of disposal for each alternative, discounting methods will be used. The annual cost is the preferred method for comparing alternative series of disbursements, as generally speaking, people seem to understand annual costs better than they understand present worth analysis. Annual costs are better understood, as the private individual, industry, and government all utilize yearly budgets. Present worth represents a lump sum covering several years expenditures and revenues. Figure 12 represents a net cash flow for a disposal alternative.

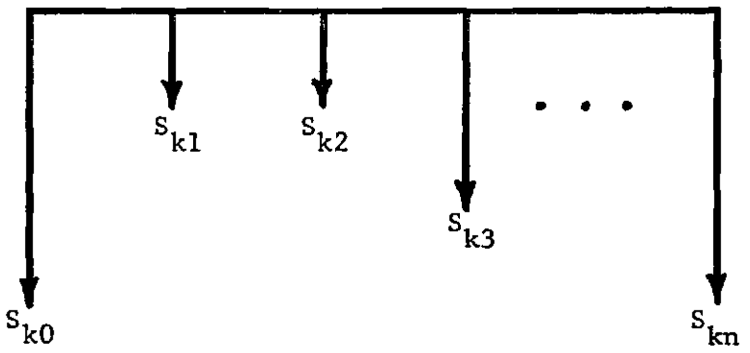


Figure 12. Net Cash Flow

Annual costs are computed from the yearly net cash flows for the expected life of the alternative in accordance with the following formula (64):

$$AC_k = \left[\sum_{t=o}^{n} S_{jk}\ (1 + i)^{-t}\right] \left[\frac{i\ (1 + i)^n}{(1 + i)^n - 1}\right]$$

where

AC_k = annual cost of alternative k

S_{kt} = cash flow for alternative k in year t

i = interest rate

n = life of alternative.

The annual cost formula transforms a nonuniform cash flow into an equivalent uniform annual cash flow. Cash flows are estimated for the length of the alternative's life and include all pertinent costs and revenues, and are presented as yearly receipts and disbursements. A more detailed discussion of relevant costs and revenues will be presented later in this section. As disposal alternatives are not profit making activities, the net cash flows will be negative.

The question of what interest rate i should be used in determining the annual cost of the alternatives must be considered. Historically, government agencies have inclined toward the selection of interest rates using the cost of borrowed money. Many large projects at the local government level are financed by the floating of tax free bonds at an interest rate between four and five percent.

Other economists argue that the interest rate should be equated at the level of existing interest rates available to the average investor, say five to seven percent. The argument states that, if the average citizen were allowed to dispose of his refuse as he sees fit, he would save money and could invest his savings in government insured investments. Opportunity costs are contained in the concept of the social cost of money. By this, social cost of money is defined in terms of the opportunities forgone in the private sector of the economy, either due to curtailed consumption or investment. The Federal government can have great effect on the private sector by the use of its fiscal and monetary tools. However, the local government's effects are minor in comparison to the Federal government's effect (65).

Society has laws prohibiting the individual disposal of refuse and requiring governmental disposal, so the opportunity cost argument is not valid in this case. Opportunity cost can be utilized when the project in question can be undertaken by both the government and private enterprise. It is recommended that the interest rate used in determining the annual cost be the interest rate used to finance that project.

When the cost estimates are made for each alternative, it is recommended that three estimates be given rather than a single point estimate. The three cost estimates should include a minimum figure, an average figure, and a maximum figure. This range of costs will be more realistic than a single point estimate. When all the cost estimates for all the alternatives are made, a cost distribution will be made for the minimum figures, the average figures, and the maximum figures.

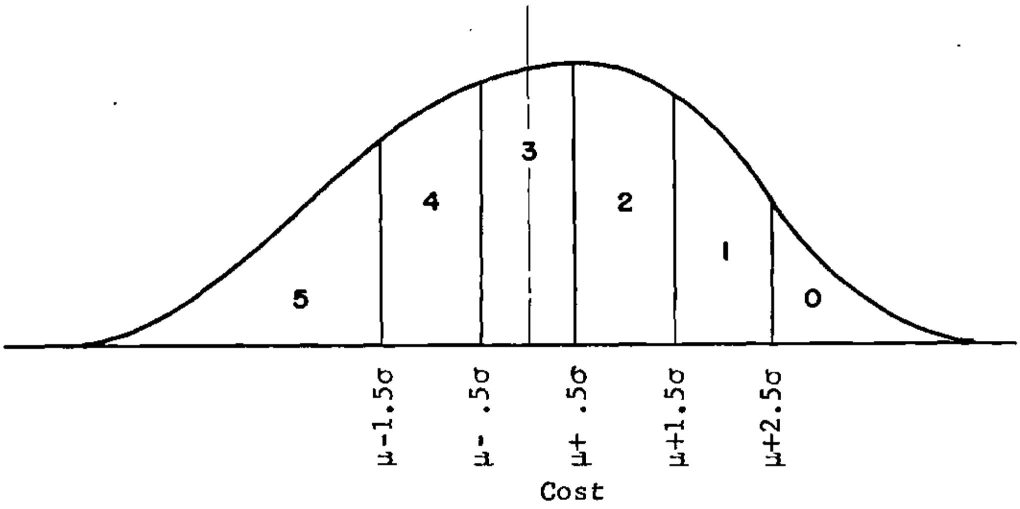


Figure 13. Cost Distribution

From the cost distribution, a mean μ and a standard deviation σ will be determined. Using the established mean μ, the distribution will be divided into six evaluation intervals using the standard deviations as shown in Figure 13. The evaluation intervals that partition each cost distribution should be of equal width except for the end intervals which reach to the ends of the distribution.

An alternative will be awarded a value V_k in accordance with the evaluation interval in which each of its cost estimates lie. The three point scores will be obtained from the three distributions, averaged, and the value V_k for the alternative will be used in Step 4 of the scoring model presented in Chapter IV.

Moore and Baker (66) have concluded that the use of equally spaced evaluation intervals, using the standard deviation, produces a satisfactory discrimination for distributions that are normal or slightly shewed to the left or right. They found, however, that the use of equally spaced intervals on distributions such as bimodel distributions provide questionable discrimination between alternatives. Proper discrimination may be obtained by the use of unequal intervals which have narrow intervals near the modes and wider intervals away from the modes. It may also be the case that unequal intervals obtained by dividing the distribution into regions based on a percentage of the area (for example one sixth of the area denotes an interval) may provide the proper discrimination for other distributions. For distribution other than normal distributions, additional investigation needs to be undertaken to determine if other than equal evaluation intervals will provide better discrimination between the alternatives. This is beyond the scope of this study.

The first step in determining the total disposal costs is to determine the amount of refuse being produced. Projections must also be made to cover future expansion. The amount of refuse being produced is essential in determining the disposal capacities of the various alternatives. The amount of refuse being produced can be obtained from historical data kept by the sanitary department. Projections up to twenty years should be considered to cover the life of the structure associated with some disposal alternatives. The Bureau of Solid Waste Management estimates the amount of refuse increases at a rate of 2.5 percent per capita per year (67). The amount of refuse being produced should be calculated in the dimension lbs/capita/year.

Once the total demand is projected, it is necessary to examine all costs related to the demands. The costs relative to most widely used disposal alternatives will be discussed in detail. Some of the disposal alternatives are still in the research and development phase and accurate historical cost data are not available.

Sanitary Landfill

The American Public Works Association has devised a formula (68) for estimating the necessary capacity of a landfill, as follows:

$$A = \frac{FR}{ZD}\left[1 - \frac{P}{100}\right]$$

where

A = landfill area per capita per year in square yards

F = an experience factor which incorporates the amount of cover material; averaging 17 percent for deep fills and 33 percent for shallow fills, with corresponding F values of 1.17 and 1.33

R = amount of refuse in lbs/capita/yr

D = average density of refuse in lbs/cu yd

P = percent reduction of refuse volume in the landfill (0 to 90 percent depending on the amount of compaction)

Z = depth of fill in yards.

To determine the amount of land required for time T, the following formula is used:

$$L = \sum_{t=1}^{T} At\ Pt$$

where

L = total land required in square yards

At = total area required per capita per year t

Pt = estimated population per year t.

The necessary information for use in this formula is normally available at the local sanitation department as statistics such as the amount disposed of and the density of the refuse are maintained. Population figures and future projection are also normally available.

Once the amount of land required is determined, the cost of purchasing the land can be determined. Projections for land should be made to cover the needs from five to ten years in the future. Generally land used for sanitary landfill is submarginal and hence the cost is lower; however, the cost of land will vary depending on the location. In larger metropolitan areas, land is in short supply and the cost of close-in land will be higher. If the land is available in the outlying regions at a lower price, the corresponding transportation costs will increase. Figure 14 illustrates this point.

If long haul disposal using sanitary landfill is contemplated, transfer stations have to be constructed at an increased cost and the transportation costs increase.

Table 1 gives some sample rail transport charges for hauling refuse to remote sites (69).

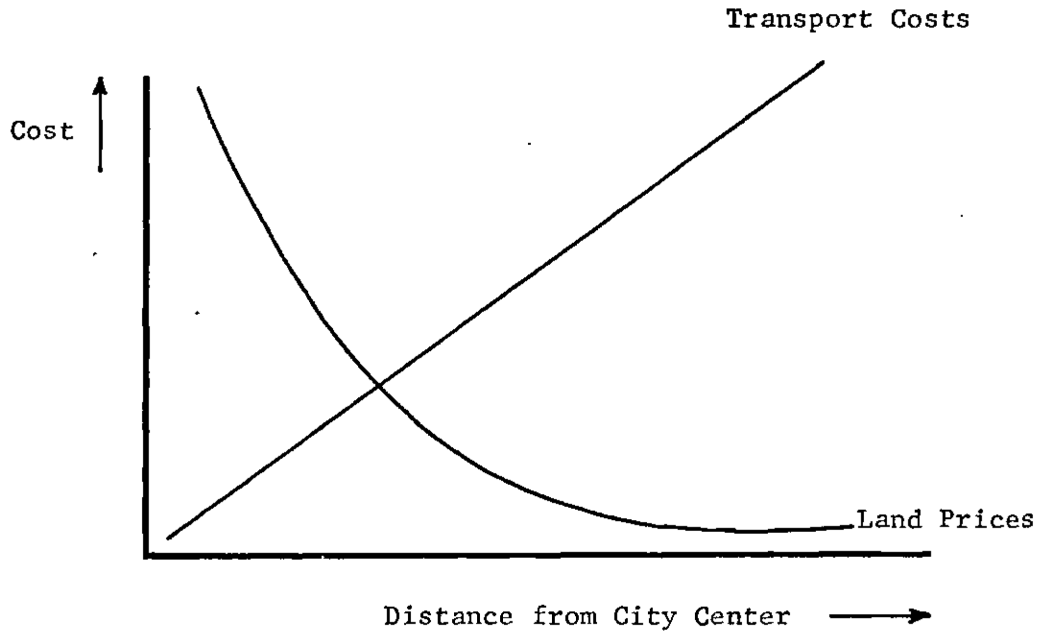


Figure 14. Cost vs Distance

Table 1. Sample Rail Transport Charges
New York Central Railroad

Mile Radius	Weight of Refuse	Cost per Ton
25	30 Tons/Car	$2.00
25	40 Tons/Car	$1.90
25	50 Tons/Car	$1.65
40	30 Tons/Car	$3.28
40	40 Tons/Car	$3.04
40	50 Tons/Car	$2.64
97	30 Tons/Car	$4.11
97	40 Tons/Car	$3.64
97	50 Tons/Car	$3.28

Costs relevant to sanitary landfill operation are:

Cla = land acquisition costs

Ctc = transportation and collection costs

Cb = building and equipment costs to include costs of depreciation

Cd = direct operating costs such as wages and operating expenses

Ci = indirect operating costs such as salaries of overhead personnel and operating costs of floating equipment

I = offsetting income such as resale of reclaimed land (changing property values should be considered).

The costs and revenues are estimated for each year of the alternative's life. Then a net cash flow is made and an equivalent annual cost is computed. This is performed three times for each alternative, using low, average, and high figures. The three annual cost estimates obtained for all the alternatives are made into three cost distributions. An alternative will be awarded a value V_k in accordance with the evaluation interval in which each of its cost estimates lie. The three point scores will be obtained from the three distributions, averaged, and the value V_k for the alternative will be used in Step 4 of the scoring model presented in Chapter IV.

Incineration

The first step in computing the cost of disposal for the incineration alternative is to determine the tonnage of waste collected per day either by actual weighing or by use of the following formula (70).

$$T = \frac{(P)\ (W)}{N}$$

where

T = tons collected per day

P = projected population of the area served

W = average amount of combustible waste generated by one person per year (A commonly used figure is 0.4 ton.)

N = number of working days in a year.

Once the tonnage collected per day is determined, the capacity required for the incinerator must then be determined. This is always expressed in the number of tons that could be incinerated in a 24 hour day.

$$C = \frac{(T)\ (24)}{H}$$

where

C = capacity required

T = tonnage of refuse per day

H = number of actual operating hours.

An example calculation is as follows:

Assume: P = 250,000 W = 0.4 ton

H = 16 hours N = 300 working days

$$T = \frac{(P)\ (W)}{N} = \frac{(250{,}000)\ (0.4)}{300} = 333\tfrac{1}{3} \text{ tons per day}$$

$$C = \frac{(333\tfrac{1}{3})\ (24)}{16} = 500 \text{ ton capacity}$$

Seasonal fluctuations and special industrial wastes will modify the above capacities. Modifications should be determined by engineering studies.

Once the capacity has been determined, the construction cost estimates can be made. Actual costs will vary by local areas. As a rule of thumb, the larger the capacity the lower the construction cost per ton (71). Some sample costs per ton are as follows:

Under 100 ton capacity	= \$5000 - \$5500 per ton
100 tons - 300 tons	= \$4000 - \$5000 per ton
Over 300 tons	= \$3000 - \$4000 per ton

For the incineration alternative, the construction cost will be the highest cost. As a rule the transport costs are lower as the incinerator can be located closer to city center. All other relevant costs are added to the construction cost to compute the total cost. Relevant costs are:

Cla = land acquisition costs

Ctc = transportation and collection costs

Cb = building and equipment costs

Cd = direct operating costs

Ci = indirect operating costs

Cnc = cost to dispose of non combustibles

I = offsetting income such as sale of steam, electricity, etc.

Again the net cash flows as developed for the life of the alternative are estimated and three equivalent annual costs obtained.

<u>Composting</u>

The costs associated with the composting alternative are quite similar to the types of costs associated with incineration. The initial costs for construction are not as high as for incineration as the buildings and equipment required are not as extensive. However, operating expenses are higher, as a considerable amount of labor is required to separate the non-compostable items prior to entering the composting process. Usually a salvage process is incorporated during the separation step and salvage materials such as paper, metals, and glass can produce offsetting income for this alternative. Experiences of compost operating companies show the existence of ready markets for salvaged metals, glass, and paper. Sale of the compost, if a market can be found, can also provide income. The market for compost is not always present even in extensive agricultural regions as the farms utilize liquid fertilizer and do not want to handle the compost.

The types of costs applicable to composting are similar to those for incineration. Additional costs are incurred in the sale and transport of salvageable material and the compost. The income received helps to offset the cost of processing. For a 300 ton daily capacity plant located in Michigan, the total production cost was \$8.47 per ton (this does not include transport and collection costs), and the offsetting income was \$3.50/ton from salvageable material and \$3.24 per ton from compost. This resulted in a net cost of \$1.73 per ton of refuse processed (72).

Public Health Protection

Solid wastes can produce undesirable biological, chemical, physical, mechanical, and psychological effects. For example, human pathogens in human feces provide a biological threat, wastes from industry pose chemical hazards, flammable materials and gases involve a physical danger through fire and explosion, and broken glass and heavy machinery utilized in the disposal system create mechanical hazards. To relate human disease, disability, annoyance or other undesirable effects to the collection, processing and disposal of solid wastes is not a simple procedure. It requires that all the steps in the pathway from solid wastes to human affliction be analyzed and validated. Figure 15 (73) illustrates in general some of the pathways that must be considered and analyzed. Figure 16 (74) illustrates in greater detail the various ways in which solid waste disposal can endanger the human.

Solid wastes have been demonstrated conclusively to be associated with some diseases in the United States. Although the incidence of disease due to waste is relatively low in this country as a whole, it is higher in certain groups, particularly those without general sanitation, including proper waste disposal means. Open dumping accounts for nearly 80 percent (75) of all waste disposal in this country. Open dumps are breeding grounds for disease vectors such as flies and rodents. These vectors find suitable harborage in the piles of exposed refuse.

In evaluating disposal alternatives under the criterion of public health, only those factors relevant to the public health and safety of humans will be considered. No measure of performance could be derived for this criterion as the value of human life cannot be quantified. Hence, this will be a quality criterion requiring subjective evaluation. Public health and safety experts can be called upon to aid in rating the various disposal alternatives. Table 2 (76) can aid the evaluators in establishing their subjective judgments.

The public health criterion is a quality criterion requiring the subjective judgments of qualified public health personnel. A method recommended by the Public Health Service to determine a quantitative assessment of a quality criterion is to break the criterion down into

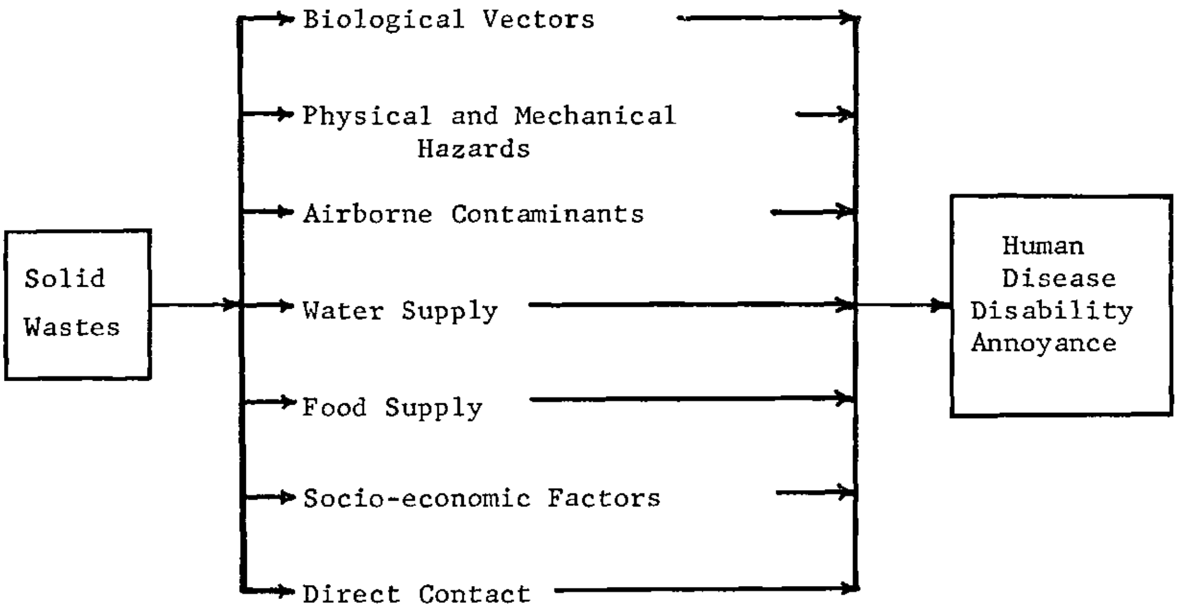


Figure 15. Pathways

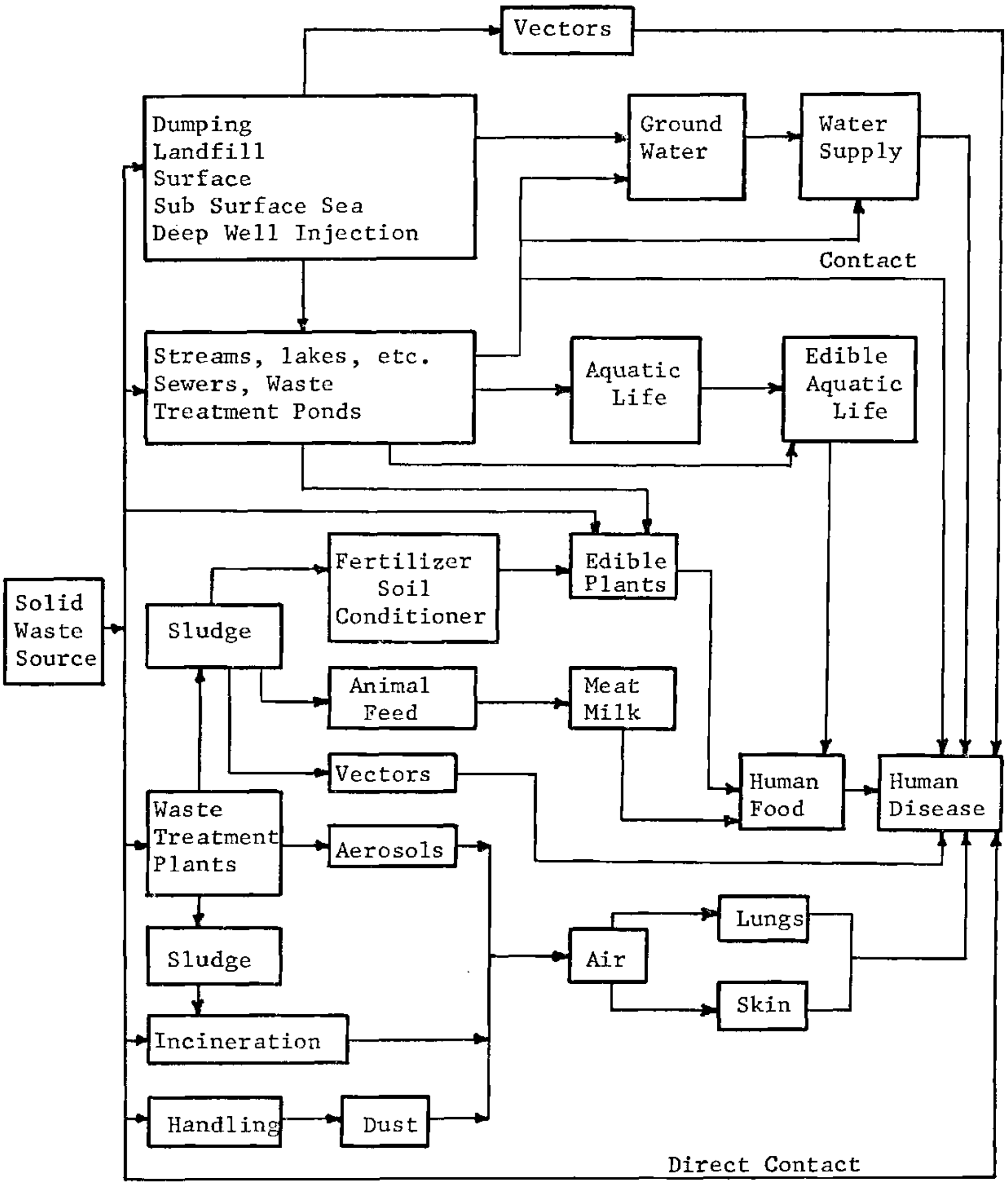


Figure 16. Solid Waste/Human Disease Pathways

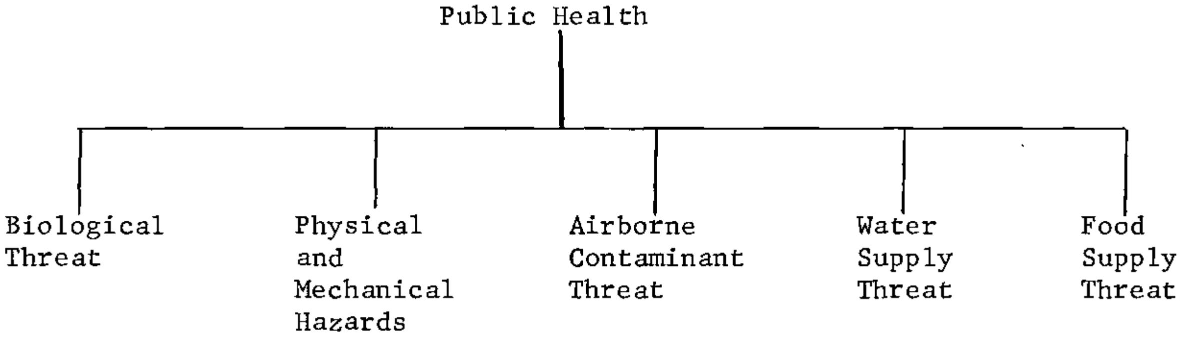
Table 2. Possible Health Problems in Solid Waste Disposal

Possible Hazard

1. Occupational hazard to workers in collection, transport, and disposal.
2. Public health and nuisance hazard associated with poor operation of land fill.
3. Odors and gases from burning fill. Vectors and odors if fill becomes fractured.
4. Public health hazard or nuisance from ground water contamination by leaching or gases from fill.
5. Occupational hazard to workers involved in reduction activities.
6. Occupational hazard to workers in salvage process.
7. Occupational hazard to workers utilizing salvaged material as a resource.
8. Public health hazard in product discharged into atmosphere.
9. Occupational hazard to workers in process.
10. Occupational hazard to workers utilizing processed recycled material.
11. Nuisances in process residues, e.g. fly ash.
12. Public health hazard in process, discharge into atmosphere.
13. Odors discharged into atmosphere.
14. Public health hazard to users of processed material.
15. Grave public health hazard because of untreated solid waste openly exposed.

Methods	Process	Nature of Possible Hazard
A. Disposal to Sink	Open Pit; Sanitary Landfill	1, 2, 3, 4, 14
B. Reduction in Volume at Source	Grinding or Compaction + Landfill	1, 2, 3, 4, 5
C. Direct Recycling	Salvage + Landfill	1, 2, 3, 4, 6, 7
D. Indirect Recycling	Pyrolization; Wet Oxidation; Rendering; Animal Feeding	1, 2, 3, 4, 8, 9, 10
E. Change of State	Incineration	1, 2, 3, 4, 9, 11, 12
F. Conversion	Composting; Digestion	1, 2, 3, 9, 13, 14
G. Diversion at Source	Direct Pollution of Land, Water, or Air	1, 2, 3, 4, 8, 15

subcriteria and then have the experts rate the subcriteria. The results of rating the subcriteria are combined into an overall rating for the criterion. The process is identical to the scoring model process and is essentially a scoring model within a scoring model. The score obtained for the subcriteria scoring model is normalized to correspond with the range of the value V_k in the decision matrix



The set of subcriteria would be ranked and weighted. The weighting would be applied in the same manner as Step 3 of the algorithm presented in Chapter IV. Values would be established for the subcriteria in accordance with the following rating scale:

15-20	for an alternative deemed to involve only slight threats to or impairment of health or safety
10-15	for an alternative involving such detriments in a moderate degree
5-10	for an alternative with considerable and an ever present threat to health and safety
1-5	for an alternative involving extreme and ever present threats to health or to life itself (77).

Each alternative would be rated under each subcriteria using this scale. The appraisal system does not set standards. It is simply a yardstick to measure and compare the quality of the disposal alternatives. The subcriteria cover the pathways from solid waste to the human. The alternatives are evaluated to see how they might affect the pathways. It is not within the scope of this work to go into great detail covering the evaluation procedure the public health official uses. This rating procedure is presented as a guide to aid the expert in his subjective evaluation.

Experienced public health officers should examine existing disposal systems that correspond to the set of alternatives being considered. The evaluation will be made on these existing systems and results modified if necessary to correspond to the local environment.

It is recommended that the value 20 be awarded to the alternative that has no threat to health. For any other ranking R that the evaluator conceives of, the amount of ill health should be proportional to 20-R. The amount of ill health in turn is proportional to the length of time people experience ill health. Estimates of the number of man-days of ill health should be made and converted to the ranking scale by normalizing the estimates. For a premature death attributed to a disposal alternative, each day of the premature demise would be equivalent to one man-day of ill health.

It must be pointed out that the majority of evaluators will be uncertain as to the amount of ill health to be expected from each of the alternatives. This should not preclude the effort being made to obtain the estimates. All that is hoped is for the evaluator to transmit to the decision makers, in the most precise manner possible, his state of knowledge. If a precise statement of what is the basis for the ranking is not made, the information contained in the rankings will be further degraded by the compound effect of imprecise questions and inadequate knowledge.

The reason for desiring a linear relationship between R and the amount of ill health is that every change in ill health will be weighted in the analysis equally. That is, a savings of one man-day of health is always treated as having equal value.

The appraisal system does not set standards. It is simply a yardstick to measure and compare the quality of the disposal alternatives. The subcriteria cover the pathways from solid waste to the human. The alternatives are evaluated to see how they might affect the pathways. It is not within the scope of this work to go into great detail covering the evaluation procedure the public health official uses. This rating procedure is presented as a guide to aid the expert in his subjective evaluation.

The results of the evaluation of the alternatives and the weighting of the subcriteria are put into a criterion decision matrix. Figure 17 illustrates the criterion decision matrix. The values V_k obtained from the subcriteria decision matrix are used in the decision matrix of Step 4, Chapter IV.

It is not meant to imply that this is the ultimate rating system. However, technical people are able and willing to express such judgments and the rather arbitrary numerical scale is satisfactory for rating alternatives under this quality criterion.

	Sub-criteria$_1$		Sub-criteria$_c$		Sub-criteria$_n$	Raw Score	Value
Weight of Subcriteria	E_1	. . .	E_c	. . .	E_n		
Alternative$_1$	F_{11}	. . .	F_{1c}	. . .	F_{1m}	G_1	V_1
:	:		:		:	:	:
Alternative$_k$	F_{k1}	. . .	F_{kc}	. . .	F_{kn}	G_k	V_k
:	:		:		:	:	:
Alternative$_z$	F_{z1}	. . .	F_{zc}	. . .	F_{zn}	G_z	V_z

Figure 17. Public Health Subcriteria Decision Matrix

where E_c = weight of subcriteria c $\quad 0 \leqq E_c \leqq 10 \quad \Sigma E_c = 10$

F_{kc} = value of alternative k for subcriteria c

G_k = raw score of alternative k

$\hat{G}_k$ = maximum possible value for G_k

V_k = normalized value for alternative k, public health criterion

B = scaling factor to bring results of subcriteria matrix into the same range as the decision matrix (B = 5)

$$G_k = \sum_{c=1}^{n} E_c F_{kc}$$

$$V_k = \frac{(G_k)\ (B)}{\hat{G}_k}$$

Prevention of Environmental Pollution

The general spirit of apathy on the part of the public towards man's effects on the environment is slowly giving way to concern. A new law, The National Environmental Policy Act of 1969, now requires that environmental considerations be taken into account in many governmental decisions. The law requires responsible agencies to prepare statements that describe in specific terms the impact a federally financed project will have on the natural environment. Further, the agency that decides the fate of such a project is required to expose its environmental impact statement to review by other concerned agencies. This law also pertains to solid waste disposal at the local level, as some of the disposal alternatives require the financial assistance of state and Federal agencies. Even if this act does not specifically pertain, the current emphasis on protecting the environment makes it mandatory that the decision makers consider the ecological impact of their decisions.

Essentially, solid waste disposal is concerned with three forms of pollution: water, air, and land pollution. While all disposal alternatives are potential polluters, each alternative affects the environment in different ways. For example, incineration is primarily an air polluter. Whereas, sanitary landfill can be a water polluter. Abandoned car bodies, glass, litter, and slag heaps are forms of land pollution and are the result of an ineffective and incomplete disposal system.

It is not within the objectives of this work to define what pollution is and to go into great detail on all the ramifications of pollution. The objective is to establish some means by which the various disposal alternatives can be evaluated with respect to the prevention of environmental pollution criteria. A suitable measure of performance has to be established.

The cost of controlling our environmental pollution will be high. A recent Harvard Business review article estimated the cost at \$275 billion over the next 32 years or approximately \$8.5 billion per year. Of this total, \$110 billion will be spent for the control of water pollution, \$105 billion for air pollution, and \$60 billion for solid waste disposal (78). Pollution, if it is not controlled, can mean added expense to the public in the form of bigger medical bills, reduced labor output, smaller livestock returns and a lower agricultural yield, depressed real estate values, higher cleaning costs, increased lighting costs due to reduced visibility, extra maintenance expense, and higher treatment expenses for facilities requiring clean air and water.

The cost criterion presented earlier in this chapter did not take into consideration the cost placed on society by pollution. This criterion will consider the pollution cost and the measure of performance for this criterion will be the expenditure required for an alternative to meet the established pollution control standards. The standards established by government represent the will of the people. The decision makers may establish stricter standards for their disposal alternatives than the standards established by law.

Air and water quality standards are set by the state, following guidelines laid down by the Federal government. As there are no overriding Federal standards, the states are free to establish their own standards. To compute the expenditure required to meet the existing standards, a thorough investigation as to how the standards affect the list of alternatives should be made. The states may require specific control devices to be installed and/or they may establish emission standards relative to specific types of emission, e.g. particulate matter, sulfur dioxide. Georgia, in addition to emission standards, has provisions in the state air laws which list the specific constriction requirements. The following is an excerpt from the Georgia laws pertaining to incinerators (79):

> (5) Incinerators:
> (a) No person shall construct a new incinerator within the state of Georgia unless:
> 1. it is a multiple chamber incinerator;
> 2. it is provided with an auxiliary burner in the primary chamber for the purposes of creating pre ignition temperatures of 800 degrees F.;
> 3. it has an efficient gas washer of the venturi, or impingement type with at least three (3) wet impingement surfaces, plus any needed dry collection or electrostatic equipment;
> 4. it has an adequate and approved induced draft fan;
> 5. it has a secondary burner to control smoke and/or odors and maintain a temperature of at least 1500 degrees F. in the secondary chamber.

In addition to the specific construction guidelines, all emission standards must be met. For each alternative, the control costs per year required for the alternative to meet the established standards must be calculated.

Table 3 illustrates the cost associated with controlling particulate emission from an incinerator by the use of control devices (80).

The evaluation process will be the same as for the cost criterion. Three cost figures in $/year will be obtained for each alternative. A cost distribution will be made and values awarded in the same manner as the cost criterion.

Table 3. Cost of Emission Control

Particulate Emissions	Control Level	Control Cost/Year
390 tons/year	0 Control Level	0
197 tons/year	1st Control Level Installing a baffled spray chamber.	19,800
86 tons/year	2nd Control Level Installing a cyclone collector.	27,800
79 tons/year	3rd Control Level Electric precipitator in series with spray chamber.	43,600
20 tons/year*	4th Control Level Add wet scrubber.	60,500
16 tons/year	5th Control Level Use a higher efficiency wet scrubber.	67,200

*Established Standard

Conservation of Resources

The economic system in the United States is largely based on a one time use of materials, with large volumes of waste generated in the process and additional quantities resulting from products discarded after a short useful life. It is now quite evident, as our natural resources are rapidly being used up, that the economy of the United States must undergo a transformation from a use and discard approach to a closed cycle of use and salvage. Raw materials taken from nature are processed into useful forms, used and ultimately find their way into the solid waste disposal system. Some of these materials are recycled; however, materials of low recovery value are either adequately deposited in disposal sinks or are inadequately discharged into the environment as pollutants of the land, water, and air.

In the past, our resources seemed limitless and the struggle upwards from a subsistence mode of life was the struggle to create the means and methods of putting these resources to use. Today, the problem is that the consumption of almost all materials is expanding at a compound rate and we are utilizing resources that are not similarly expanding. This rapid use of natural resources cannot go on indefinitely. We must either cut down on our consumption or recycle our waste.

European countries, which have lived with a shortage of natural resources, are much more advanced in the technology and use of waste recycling. This nation of waste makers must change its habits and start to effectively conserve its natural resources. What this generation wastes and does not reuse, the next may have to pay dearly for. It is quite safe to say that the conservation criterion is overlooked when disposal alternatives are evaluated, as the vast majority of our disposal systems conserve nothing.

The ultimate in waste disposal is the reuse of all materials. Unfortunately, this goal is a long way from realization. The fact exists that an enormous quantity of materials could be reused, if it could be separated efficiently and economically from refuse. Therefore, it is important that conservation of materials be considered as a criterion in the selection of a disposal method.

The measure of performance that is applicable to this criterion is the percent of the refuse produced that is effectively reused or recycled. The salvage process effectively separates usable material and prepares the reusable material to be directly recycled. Other processes such as composting and pyrolysis transform the refuse into another form that can be effectively used. Incineration, that effectively uses the heat of combustion, changes the combustible refuse into usable energy.

The evaluation process for the conservation of materials criterion will be handled in the same manner as the cost criterion. Percentage estimates will be obtained, a distribution will be made, and the alternative awarded values respective to their position in the distribution.

Public Sentiment and Acceptance

The public creates solid wastes, discards them, and expects efficient, effective, uncomplicated, nuisance free, and above all, an economical collection and disposal system. The public is intimately involved in the solid waste disposal system. The system is paid for by the public, the collection portion of the system affects every household, and the disposal sites closely affect a certain portion of the public. Past mismanagement of solid waste disposal has stimulated significant negative reaction on the part of the public. This negative reaction has fostered some misconceptions towards solid waste disposal. For example, the public often fails to distinguish between obnoxious dumps and effectively operated sanitary land fills.

In evaluating the various disposal alternatives, the decision makers should attempt to gauge the attitudes and motivations of the public. Acceptability of a method of refuse disposal by the public is important, since the choice of methods may well hinge upon how easy it is to get approval of it. The initiative for different methods of disposal may come from the public. Opposition may have already formed against specific disposal methods. These sources of opposition should be located and the reason for the opposition should be determined. Sources of opposition include the following types of citizen. People who do not want disposal sites near them, as they feel the disposal facility lowers their property values. People who do not want the local government to spend money even if pollution occurs or public health is impaired. People who resist any change and who believe no solution is possible. People who have inadequate or erroneous information. People who are politically opposed to those advocating new disposal alternatives. Finally, those who have lost confidence in the solid waste disposal system because of past practice.

Armed with information as to how the public feels concerning solid waste disposal, the alternatives can be evaluated with respect to their possible acceptance. In many communities, public acceptance of a particular disposal method is the most important factor in deciding whether the method will exist. If the alternative that is finally selected is weak in the area of public acceptance, an effective public information program can be launched in an attempt to sell the decision and overcome the resistance.

The public acceptance criterion will be handled as a quantifiable criterion. Information must be obtained to indicate to the decision maker the public's feeling. The measure of performance will be the percentage of the interviewed public that accepts the disposal alternative.

A questionnaire will be used to gain information on the public's attitude towards the disposal alternatives. An appropriate sample of the voting public can either be sent written questionnaires or telephone contacts can be made. The questionnaire can be designed to get the information desired to aid the decision makers in making their evaluation under this criterion. A sample questionnaire is shown in Appendix C.

The questionnaire has been designed to get results in the form of the percentage of public sampled accepting a particular disposal alternative. The decision makers, who are attuned to measurement of the public's sentiments, should be included in examining the results of the questionnaire. The questionnaire should be designed with questions to test the public's acceptance on the particular alternatives being considered. The evaluation process for the public sentiment and acceptance criteria will be handled in the same manner as the cost criteria. For example, questions 20-28 from the sample public sentiment measurement questionnaire, Appendix C, would be used to obtain the percentage estimates. From these estimates, a distribution will be made, and the alternatives awarded values respective to their position in the distribution.

Reliability

Reliability is defined as the probability of a successful operation of a device or system in the manner and under the conditions of intended customer use. Reliability is a relevant criterion as unreliability has consequences in cost, time wasted, the psychological effect of inconvenience, and in the case of solid waste disposal the possible endangerment of public health. The reliability of the solid waste disposal system is equal to the product of the probabilities of successful operation of each subsystem and each individual or device in each subsystem (81). The subsystems that are applicable in the solid waste disposal system are the collection system, the transportation system, and the disposal system. Each one of these subsystems is made up of men and equipment, which have a bearing on the reliability of the entire system.

Granted, that the reliability of this particular system is not as important as some of the aerospace systems, because the consequences of unreliability are not a life and death affair. However, the reliability criterion should not be discarded as cost, time wasted, and the public health involved. The public expects a system to be reliable in that it wants its refuse picked up on time, and it wants the refuse to be adequately disposed of.

Unreliability can be prevented through proper planning and design. Systems engineering can be used to adequately plan and design so that the components can be integrated into the system. Redundancy or what might be called inbuilt flexibility can be designed into a system to afford a measure of safety. This implies that the more alternative components there are, the greater the probability that one of them, and hence the system, will operate effectively. For example, if a particular disposal alternative has only one incinerator as the sole means of disposal and this incinerator is down for maintenance, the system's reliability will be lowered. Management control and communication are also important in preventing unreliability. The more complex an organization is, the more control is necessary to insure the effective operation of all the interacting subcomponents. As humans are involved in this system, human engineering and reliability education are also important to prevent unreliability. The system can be designed to minimize human error by making the assembly, operation, and maintenance of the system as straightforward as possible.

The measure of performance applicable to the reliability criterion will be the probability of a successful operation of the particular disposal alternative. Standard reliability estimation techniques such as continuous experimental designs, random balance designs, multiple balance design, and response surface experimentation can be used by personnel schooled in these techniques to obtain the reliability estimates. Once the estimates are obtained, a reliability distribution can be made, and the alternative evaluated in the same manner as the cost criterion. If the extra cost of employing skilled reliability estimators is not warranted, this criterion can be handled as a quality criterion. A rating system can then be used to evaluate the alternatives (82).

Implementation Considerations

This criterion encompasses several factors relevant to the implementation of the disposal alternatives. Included in this criterion are legal restraints, funding considerations, regional planning aspects, and political considerations which bear on the decision environment. This criterion will be broken down into subcriteria and each subcriterion will be used to evaluate the alternatives. The criterion will be broken down as follows:

Implementation Criterion

- Legal Restriction
- Outside Funding Assistance Considerations
- Regional Planning Aspects
- Community Goals

Legal restraints bearing on the decision process may exist. Federal, state, and local laws may prohibit certain forms of disposal or control varying aspects of them. Zoning laws may affect the location of certain disposal facilities. A thorough investigation of all applicable ordinances and laws should be made during the evaluation.

Values F_{kc} will be awarded as follows: five for no legal restrictions; zero for legal restrictions affecting the alternative. If legal restrictions exist, a superscripted number will be added to the value to indicate that there are legal complications and that an explanation is added. If the decision makers have the authority to change the legal restrictions, and if the subject alternative is selected, appropriate changes can be made if deemed necessary. If the authority to change the legal restriction does not rest with the decision makers, and the appropriate change cannot be made, the alternative will be dropped from consideration.

Federal and state funding assistance may be available for certain alternatives. The Federal government makes grants available to communities that are experimenting with new and innovative disposal systems. Additional state funds may be available that provide alternatives. An investigation into the types of financial assistance available should be made for each alternative.

All alternatives will be examined and estimates will be made on the amount of assistance money available. These amounts will range from zero to the maximum amount. F_{kc} values will be awarded in accordance with the following normalization formula:

$$\frac{\text{(Assistance Estimate) (5)}}{\text{(Maximum Assistance Estimate)}} = F_{kc}$$

In metropolitan areas, communities which for many years have indulged in the practice of depositing their wastes in other jurisdictions are finding that they no longer can use these sites and are either faced with the prospect of finding other methods of disposal which can be used within their jurisdiction or are faced with disposing of their waste at great distance. These problems have started a trend toward the regional planning approach, whereby disposal sites and systems are integrated into a regional master plan. The decision makers should consider the regional planning impact of their alternatives to insure that their alternatives are compatible. F_{kc} values will be awarded to the alternatives as follows: five for compatibility with regional planning aspects; and zero for noncompatibility. Explanations will be given for zero values.

There may exist in the local community certain general goals, not directly related to the disposal system, that the community is attempting to achieve such as an increase in employment, the development of more recreational area, or area beautification. Certain disposal alternatives being evaluated may contribute to the achieving of these goals. The alternatives should be examined to see if they fit into existing urban development plans and the general goals of the community. F_{kc} values will be awarded as follows: five for compatibility with community goals; zero for noncompatibility. Explanations will be given for zero values.

The results of the evaluation of the alternatives and the weighting of the subcriteria are put into a criterion decision matrix. The implementation criterion decision matrix is of the same form as the public health criterion matrix. The values V_k are obtained in the same manner and are utilized in the decision matrix of Step 4, Chapter IV.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In spite of recent advances in management science, decision making still remains essentially an art. As an art, it is open to controversy. Any selection technique which is utilized to aid a decision maker will have its weak points. These weak points offer an opening for academic attack by those with divergent views. Yet, there is little evidence to suggest that any one model form is preferable to any other for all the various evaluation and selection decisions that arise within local government.

Highly mathematical and complex techniques have been developed to aid the decision maker in arriving at his decision. These techniques are often limited in their scope and are just as effective as the data that they utilize. Additionally, their complexity often discourages their use as the decision maker is essentially unsophisticated and will normally reject any evaluation process that he does not understand. Often the more complex techniques involve an expenditure of a considerable amount of money and time. Both of which are often not available to the decision maker. It must also be kept in mind that whatever technique is utilized, the results achieved are nothing more than recommendations. The final decision is still made by the decision maker.

A government can determine its policies most effectively if it chooses rationally among alternative courses of action, with as full knowledge as possible, of the implications of those alternatives. The scoring model represents a rational approach for the decision maker to take in choosing among alternative courses of action. The model evaluates the alternatives from a broad range of criteria, thereby providing a wide range of information to the decision maker. This ability to furnish information in a compact form is a significant advantage of the scoring model. The scoring model can also utilize subjective or qualitative factors that bear upon the decision. Scoring models allow the use of simple low cost methods of data acquisition. Where the situation does not permit a meaningful point estimate of performance to be made, interval estimates can be used.

The use of subjective evaluation in the model is indeed a point of controversy. Objective ratings are preferred to subjective ratings. However, there are many cases where decision making does not lend itself to deriving more objective criteria or where available objective criteria are not especially meaningful. Decision makers which utilize other types of more objective models either omit the relevant qualitative factors, or consider these factors in a less analytical way than the scoring model.

Recommendations

The model should be applied to a real life situation to verify its validity. Use under a real world situation may give new insights to the problems of measurement and implementation of this model. In addition, the appropriateness of this model would be more clearly understood.

Additional investigation should be made into the method of dividing distributions into evaluation intervals. It has been found that the division of normal distribution into equal intervals using the standard deviation produces satisfactory results. For distributions that are not normal, different division schemes need to be determined. The use of unequal intervals should be investigated to see if these intervals provide adequate discrimination.

The subjective criteria used in this thesis, public health protection, and implementation considerations, should be further investigated to determine if there is a more thorough way to evaluate the alternatives under these criteria. The subcriteria breakdown used in this paper is rather arbitrary and additional research to develop a procedure to improve the selection of subcriteria would be very useful. These criteria are often overlooked in solid waste management and as a result there has been little research into the effects these criteria have on the decision process.

Another area to be considered is the use of qualitative criteria. This is admittedly one of the weak points of the model. It would be more preferable to replace these criteria with objective criteria. This is especially true in the area of public health protection and implementation considerations. Could these essentially subjective criteria be adequately measured by performance measures that are more objective in nature?

As a final topic, consider the possibility of comparing the scoring model with other classes of models utilizing the same decision environment. This comparison test would answer the following question: Do scoring models give results for given alternatives and the same input data, consistent with the results produced by other model classes?

APPENDICES

APPENDIX A

DEFINITION OF TERMS

The following is a list of terms extracted from an article published in Public Works (83) that are commonly used throughout this thesis.

Air Pollution--The presence in the atmosphere of any form of contaminant which may adversely affect the public health, safety or welfare; or which may be injurious to human, plant, or animal life, or to property; or which unreasonably interfers with the comfortable enjoyment of life or property.

Agricultural Waste--The solid waste resulting from the production of agricultural products.

Commercial Waste--All solid waste generated from establishments engaged in business.

Composting--The process in which solid waste is ground up and biologically decomposed to yield a stable nuisance free soil enricher.

Construction and Demolition Waste--Solid wastes resulting from construction, repair, demolition operations on houses, buildings, pavements, and other structures.

Domestic Waste--Garbage and rubbish that originates in the private or apartment household.

Garbage--Waste resulting from the preparation, cooking, and consumption of foods, market refuse, waste from handling, storage, and sale of produce.

Hazardous Waste--Solid waste with certain dangers. Included are chemicals, explosives, pathological wastes and radioactive materials.

Incineration--The process of burning combustible waste to a gas and an inert residue.

Industrial Waste--All solid waste resulting from manufacturing and industrial processes.

Open Dump--Land disposal site which lacks proper management and is not operated with compaction and cover.

Processing of Wastes--Any technology applied for the purpose of reducing the bulk of solid waste material or designed to convert part or all of the waste materials for reuse.

Refuse--All materials which are discarded as useless.

Residue--Solid materials and unburned organics remaining after incineration.

Rubbish--All solid waste except garbage and other decomposable matter.

Salvaging--The controlled removal of material from solid waste processing or disposal site.

Sanitary Landfill--A land site on which sound engineering principles are applied to bury deposits of solid waste without creating public health problems, or safety hazards or nuisances.

Solid Waste--Garbage, refuse, and other discarded materials resulting from industrial, commercial, agricultural and residential activities.

Vector--An animal or insect which transmits infectious diseases from one person or animal to another. The transmission is accomplished by biting the skin or mucous membrane or by depositing infective material on the skin, on food, or on other objects.

Water Pollution--Contamination of any waters such as will create a nuisance or to render such waters harmful, detrimental, or injurious to public health, safety, or welfare, or to endanger animal and plant life. The contamination results in the alteration of the physical, chemical, or biological properties of the waters, or changes in temperature, taste, color, or odor thereof.

APPENDIX B

EXAMPLE OF MODEL USAGE

The example which follows illustrates the use of the decision model developed in Chapter IV. The environment for the example is a metropolitan area having a population of 750,000. The following alternatives have been suggested and will be evaluated by the decision model:

1. Primarily landfill, utilizes existing incinerator. Incinerator will be phased out and all future disposal will be via sanitary landfill.

2. Primarily incineration, existing landfills will be used to dispose of noncombustibles and residue from the incinerators. Necessary pollution control devices are to be added.

3. Primarily composting, with a salvage process prior to the composting process. Refuse that cannot be composted goes to sanitary landfill.

4. Salvage operation, shredding of non-salvageable items and then landfill.

5. Salvage operation, shredding of non-salvageable items and then incineration.

6. Dual disposal of sewage and garbage, and then wet oxidation treatment. The remaining refuse will be salvaged and incinerated. This alternative requires installation of home garbage grinders and an increased capacity sewage disposal system.

7. Use of home compaction, central compaction, and long haul disposal by rail to remote sanitary landfills.

8. Open pit disposal.

9. Incineration with the use of the heat of combustion.

Step 1

The criteria suggested in Chapter IV will be used in this example.

Step 2

It is assumed that all appropriate preliminary planning studies have been performed and the data required for use in the model has been obtained.

Step 3

The decision makers have ranked the criteria and the results of the ranking and the composite weighting process is shown below.

Individual Weighting

	Decision Makers					
	P_{c1}*	P_{c2}	P_{c3}	P_{c4}	P_{c5}	P_{c6}
Cost (C)	9	7	10	9	8	10
Public Health Protection (PH)	8	9	4	8	5	7
Prevention of Environmental Pollution (PP)	8	10	8	9	8	8
Public Sentiment (PS)	7	4	8	10	7	5
Conservation of Resources (CR)	4	5	3	7	4	2
Implementation Considerations (IC)	4	2	9	8	7	9
Reliability (R)	1	8	3	5	10	4

*P_{cd} = rating given by decision maker d to criterion c

W_{cd}*

	Decision Makers 1	2	3	4	5	6	$\sum_{d=1}^{6} W_{cd}$
C	.220	.156	.222	.161	.163	.222	1.144
PH	.195	.200	.088	.142	.102	.156	.883
PP	.195	.222	.178	.161	.163	.178	1.097
PS	.171	.089	.178	.179	.143	.111	.871
CM	.098	.111	.067	.125	.082	.044	.527
IC	.098	.044	.200	.142	.143	.200	.827
R	.023	.178	.067	.090	.204	.089	.651

W_c**

C	1.91
PH	1.47
PP	1.83
PS	1.45
CR	.87
IC	1.38
R	1.09

$$**W_c = \frac{P_{cd}}{\sum_{c=1}^{m} P_{cd}}$$ example $$W_{11} = \frac{9}{41} = .221$$

$$**W_c = A \frac{\sum_{d=1}^{h} W_{cd}}{\sum_{d=1}^{n} \sum_{c=1}^{m} W_{cd}}$$ example $$W_{ph} = \frac{10(.883)}{6} = 1.47$$

Step 4

The evaluation of the set of alternatives under the applicable criteria is as follows:

Cost Criterion (Millions of dollars per year)

Alternative	Low	Average	High
1	1.11	1.31	1.52
2	1.63	1.70	1.92
3	1.47	1.62	1.93
4	1.20	1.30	1.40
5	1.54	1.65	1.80
6	1.83	2.00	2.24
7	1.60	1.82	2.02
8	.81	1.00	1.27
9	1.54	1.65	1.83

μ Low = 1.41 μ Avg. = 1.56 μ High = 1.77

σ Low = .30 σ Avg. = .30 σ High = .31

Range	Low	Average	High	Value
	over 2.16	over 2.31	over 2.54	0
	1.86-2.16	2.01-0.31	2.23-2.54	1
	1.56-1.86	1.71-2.01	1.92-2.23	2
	1.26-1.56	1.41-1.71	1.62-1.92	3
	.96-1.26	1.11-1.41	1.31-1.62	4
	under .96	under 1.11	under 1.31	5

Value for Cost Criterion

Alternative	Value			V_c
	Low	Average	High	
1	4	4	4	4.0
2	2	3	2	2.3
3	3	3	2	2.6
4	4	4	4	4.0
5	3	3	3	3.0
6	2	2	1	1.7
7	2	2	2	2.0
8	5	5	5	5.0
9	3	3	3	3.0

Prevention of Environmental Pollution Criterion ($/year)

Alternative	Low	Average	High
1	25,000	30,000	35,000
2	50,000	70,000	90,000
3	15,000	25,000	30,000
4	10,000	15,000	20,000
5	50,000	60,000	75,000
6	70,000	100,000	120,000
7	20,000	35,000	30,000
8	120,000	150,000	170,000
9	50,000	60,000	70,000
	μ Low = 45,600	μ Avg. = 60,600	μ High = 71,100
	σ Low = 32,400	σ Avg. = 40,200	σ High = 47,000

Range	Low	Average	High	Value
	over 126,600	over 161,100	over 188,600	0
	94,200-126,600	120,900-161,100	141,600-188,600	1
	61,800-94,200	80,700-120,900	94,600-141,600	2
	29,400-61,800	40,500-80,700	41,000-94,600	3
	0-29,400	0-40,500	0-47,000	4
				5

Value for Prevention of Environmental Pollution Criterion

Alternative	Value			V_k
	Low	Average	High	
1	4	4	4	4.0
2	3	3	3	3.0
3	4	4	4	4.0
4	4	4	4	4.0
5	3	3	3	3.0
6	2	2	2	2.0
7	4	4	4	4.0
8	1	1	1	1.0
9	3	3	3	3.0

Public Health Criterion

Criterion Decision Matrix

	Biological Threat	Airborne Contaminant Threat	Water Supply Threat	Food Supply Threat	Physical and Mechanical Hazard	Raw Score	V_k
	2.8	2.3	1.9	1.7	1.3		
Alt. 1	8	11	8	12	15	102.8	2.6
Alt. 2	11	8	11	17	10	112.0	2.8
Alt. 3	5	15	11	10	8	96.8	2.4
Alt. 4	18	14	8	13	12	135.5	3.4
Alt. 5	8	8	11	12	5	88.6	2.2
Alt. 6	19	14	11	15	17	153.9	3.8
Alt. 7	8	10	9	7	8	84.8	2.1
Alt. 8	1	4	2	1	11	31.8	0.8
Alt. 9	11	6	12	12	5	94.3	2.4

Public Sentiment and Acceptance Criterion (% stating yes to appropriate question)

Alternative	Question
1	65
2	70
3	85
4	75
5	80
6	50
7	55
8	40
9	75

$\mu = \frac{\Sigma X}{N} = 66.1$ $\sigma = \sqrt{\frac{\Sigma (X - \bar{X})^2}{N}} = 14.1$

Range		Value
over $\mu + 1.5\sigma$	87.3	5
$\mu + .5\sigma$ to $\mu + 1.5\sigma$	73.2 - 87.3	4
$\mu - .5\sigma$ to $\mu + .5\sigma$	59.1 - 73.2	3
$\mu - 1.5\sigma$ to $\mu - .5\sigma$	45.0 - 59.1	2
$\mu - 2.5\sigma$ to $\mu - 1.5\sigma$	30.9 - 45.0	1
under $\mu - 2.5\sigma$	30.9	0

Value for Public Sentiment and Acceptance Criterion

Alternative	Value
1	3.0
2	3.0
3	4.0
4	4.0
5	4.0
6	2.0
7	2.0
8	1.0
9	4.0

Implementation Criterion

	Funding Considerations	Legal Restrictions	Regional Planning Aspects	Community Goals	Raw Score	V_k
	3.5	2.7	2.2	1.6		
Alt. 1	5	5	0	5	39.0	3.9
Alt. 2	5	5	5	0	42.0	4.2
Alt. 3	0	5	0	5	21.5	2.2
Alt. 4	5	5	0	5	39.0	3.9
Alt. 5	5	5	5	5	50.0	5.0
Alt. 6	0	5	5	5	32.5	3.2
Alt 7.	5	0	5	5	36.5	3.6
Alt. 8	5	0	0	0	17.5	1.8
Alt. 9	5	5	5	0	42.0	4.2

Reliability Criterion

Alternative	Low	Average	High	(%)
1	80	85	90	
2	90	95	98	
3	75	80	85	
4	80	85	90	
5	89	93	97	
6	83	87	90	
7	87	90	92	
8	98	99	99	
9	89	92	95	

μ Low = 85.6 μ Avg. = 89.5 μ High = 92.8

σ Low = 6.5 σ Avg. = 5.4 σ High = 4.3

Range	Low	Average	High	Value
	over 95.3	over 97.6	over 99.2	5
	88.8-95.3	92.2-97.6	94.9-99.2	4
	82.3-88.8	86.8-92.2	90.6-94.9	3
	75.8-82.3	81.4-86.8	86.3-90.6	2
	69.3-75.8	76.0-81.4	82.2-86.3	1
	under 69.3	under 76.0	under 82.8	0

Value for Reliability Criterion

Alternative	Value			V_k
	Low	Average	High	
1	2	2	2	2.0
2	4	4	4	4.0
3	1	1	1	1.0
4	2	2	2	2.0
5	4	4	4	4.0
6	3	3	3	2.7
7	3	3	3	3.0
8	5	5	5	4.7
9	4	3	4	3.7

Conservation of Resources Criterion (% of materials reused)

Alternative	Low	Average	High
1	0	0	0
2	0	0	0
3	60	67	75
4	11	15	20
5	11	15	20
6	75	80	85
7	0	0	0
8	0	0	0
9	60	65	70

μ Low = 24.1 μ Avg. = 26.9 μ High = 30.0

σ Low = 29.5 σ Avg. = 31.7 σ High = 35.2

Range	Low	Average	High	Value
	over 97.9	over 74.5	over 82.8	5
	68.4-97.9	42.5-74.5	47.6-82.8	4
	38.9-68.4	10.8-42.5	12.4-47.6	3
	9.4-38.9			2
				1
	under 9.4	under 10.8	under 12.4	0

Value for Conservation of Resources Criterion

Alternative	Value			V_k
	Low	Average	High	
1	0	0	0	0.0
2	0	0	0	0.0
3	3	4	4	3.7
4	2	3	3	2.7
5	2	3	3	2.7
6	4	5	5	4.7
7	0	0	0	0
8	0	0	0	0
9	3	4	4	3.7

When all the alternatives are evaluated under all the criteria, a decision matrix is made.

Decision Matrix

	C	PP	PH*	PS	IC*	R	CR	
	1.91	1.83	1.47	1.45	1.38	1.09	.87	Score
Alt. 1	4.0	4.0	2.6	3.0	3.9	2.0	0	30.7
Alt. 2	2.3	3.0	2.8	3.0	4.2	4.0	0	28.5
Alt. 3	2.6	4.0	2.4	4.0	2.2	1.0	3.7	28.9
Alt. 4	4.0	4.0	3.4	4.0	3.9	2.0	2.7	35.7
Alt. 5	3.0	3.0	2.2	4.0	5.0	4.0	2.7	33.8
Alt. 6	1.7	2.0	3.8	2.0	3.2	2.7	4.7	26.8
Alt. 7	2.0	4.0	2.1	2.0	3.6	3.0	0	25.4
Alt. 8	5.0	1.0	0.8	1.0	1.8	4.7	0	21.6
Alt. 9	3.0	3.0	2.4	4.0	4.2	3.7	3.7	33.6

*Qualitative Criteria

<u>Step 5</u>

The score for each alternative is obtained. This score is a measure of the relative worth of the alternative.

<u>Step 6</u>

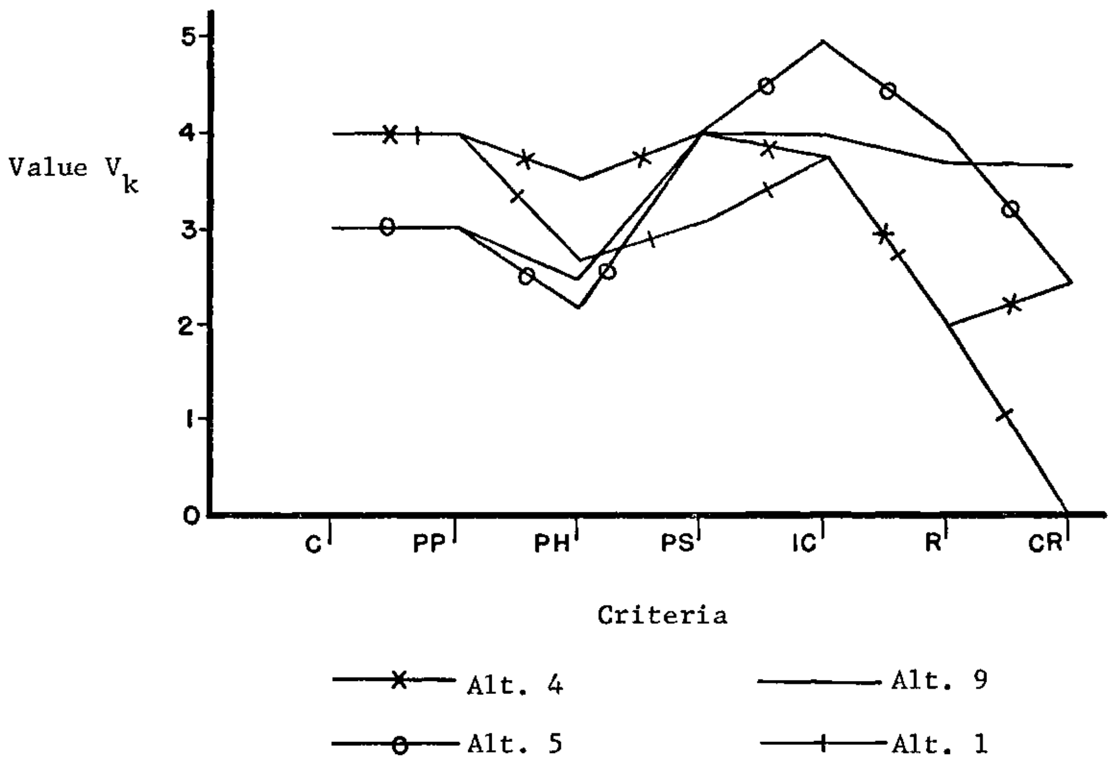
The alternatives are then presented in order of worth based upon the composite score obtained.

Order of Worth	Score
Alt. 4	35.7
Alt. 5	33.8
Alt. 9	33.6
Alt. 1	30.7
Alt. 3	28.9
Alt. 2	28.5
Alt. 6	26.8
Alt. 7	25.4
Alt. 8	21.6

Step 7

An alternative dominance graph was made for alternatives 4, 5, 9, and 1.

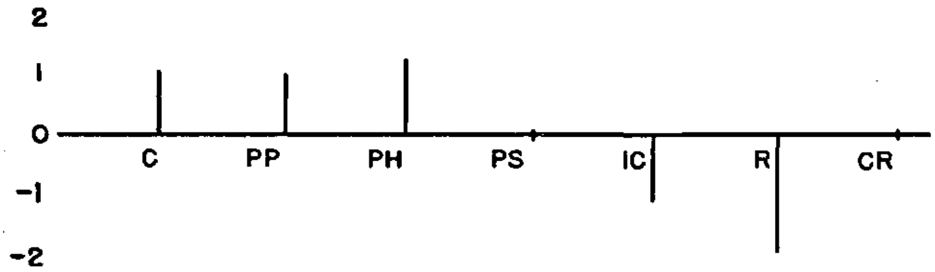
Alternative Dominance Graph



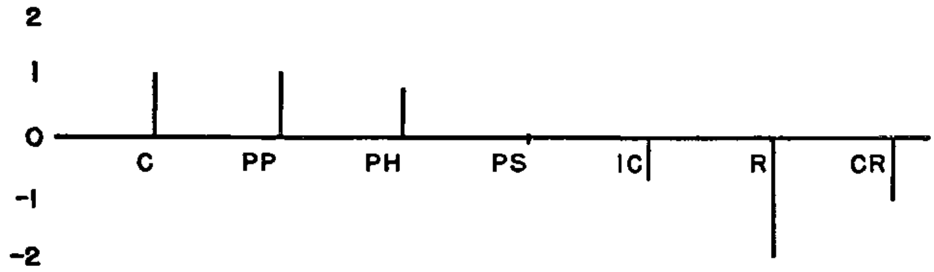
From the results of the graph, alternatives 4, 5, and 9 were determined to be dominant. Difference profiles were made for these alternatives.

Difference Profiles

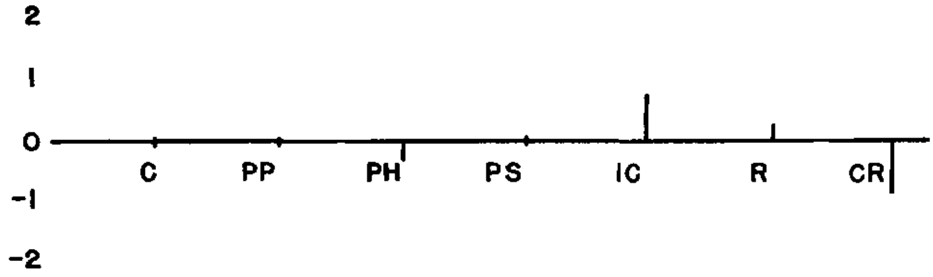
Alt. 4-5



Alt. 4-9



Alt. 5-9



Step 8

The decision is made by the decision makers and the decision is communicated to the public in the form of an operational solid waste management plan. For this example, Alternative 4, sanitary landfill, preceded by a salvage operation and shredding of non-salvageable items, was chosen.

APPENDIX C

SAMPLE PUBLIC SENTIMENT MEASUREMENT QUESTIONNAIRE

PUBLIC SENTIMENT MEASUREMENT QUESTIONNAIRE

Hello, I'm ____________________ from the ___________________ Sanitation Department. We're conducting a survey in this area in regards to the pick up and disposal of solid waste. I'd like to get your opinions on some matters of interest in this subject area. Your responses will be helpful to us in the planning of new systems and helping to improve this present system.

1. How long have you lived in this area? ____________________________
2. Which city do you live in? ____
3. Do you live in:

   _____ a single family house   _____ a duplex

   _____ an apartment   _____ other ______________________
4. How many live in this household? ________________________________
5. Do you have garbage or refuse collection service? _____yes _____no
6. How often is it collected? _____once/week _____twice/week

   _____oftener
7. Do you feel that this is sufficient? _____yes _____no
8. Do you have any complaints about the method of collection?

   ____
9. Would you be willing to have curb side pick up? _____yes _____no
10. If no, what is main objection? __________________________________

11. Are you required to separate the garbage from the rest of the the refuse? _____yes _____no

12. If no, would you be willing to separate the garbage from the rest of the refuse? _____yes _____no

13. Would you be willing to separate paper from the rest of the refuse? _____yes _____no

14. Do you dispose of any of your own refuse? _____yes _____no

15. If yes to 14, how? ____

16. If yes to 14, do you have ease of access to disposal facility: _____yes _____no

17. Which of the following disposal methods are you familiar with:

    _____open pit   _____charcoal production

    _____sanitary landfill   _____salvage

    _____incineration   _____pyrolysis

    _____composting   _____animal feeding

    _____dual disposal of sewage and garbage, requires a home garbage disposal unit

    _____compaction, requires a home compactor

    _____other

18. Do you know which disposal method your __________ uses? _____no _____yes which one_______________

19. If yes to 18, are you satisfied with the method of disposal? _____yes _____no

20. Would you approve of disposal by the use of sanitary landfill in a suitable location? _____yes _____no

21. Would you approve of the construction of disposal incinerators?

    _____yes _____no

22. Would you approve of disposal by the composting method?

    _____yes _____no

23. Would you approve of a salvage operation combined with sanitary

    landfill? _____yes _____no

24. Would you approve of a salvage operation combined with an incinera-

    tor? _____yes _____no

25. Would you approve of a system which would dispose of your garbage through your sewer system? This would require you to purchase a garbage disposal unit. However, your refuse collection bill would be reduced ____% per year. _____yes _____no

26. Would you purchase a home compactor if your refuse collection bill was reduced ____%? The refuse would be disposed of at remote sanitary landfills requiring long distance transport by rail.
    _____yes _____no

27. Should the city dispose of your refuse in an open pit?

    _____yes _____no

28. Would you approve of disposal by incineration? The heat of combustion produced would be used to produce electricity.

    _____yes _____no

29. If a disposal method, which was higher in cost yet its effect on the environment was lower was proposed, would you be willing to support the increased cost?

    _____yes _____no

30. Do you think the city should attempt to salvage any of the refuse?

    _____yes _____no

31. If you disapproved of any of the suggested disposal methods covered in questions 20-28, would you state the reasons for your disapproval?

    Question _____ ______________________________________

    Question _____ ______________________________________

32. Would you be willing to purchase home disposal equipment if your refuse collection bill was reduced?

_____yes _____no

Add any other pertinent questions applicable to the local area and the disposal alternatives being considered.

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